Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA)

B.G. Lucas, S. Verrin, and R. Brown (Editors)

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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

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ABSTRACT

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

This report provides an overview of physical and biological ecosystems in the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is one of several Large Ocean Management Areas created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada. PNCIMA includes the Pacific coast of British Columbia from the Canada-Alaska border in the north to Brooks Peninsula on NW Vancouver Island and Quadra Island and Bute Inlet in the south; from the outer limit of the continental slope in the west to the coastal watersheds in the east.

PNCIMA is characterized by steep and rugged coastal mountains, abundant offshore islands, a coastline dominated by rocky shores with few sand and gravel beaches, valleys and fjords that extend to the ocean floor, and a glacially scoured continental shelf with cross cutting troughs. The Pacific Ocean moderates the climate, resulting in warm wet winters and cool summers. PNCIMA is located in a transition zone between two areas, one dominated by Alaska Coastal Current downwelling (north), and the other by California Current upwelling (south). PNCIMA's semi-enclosed basin, varied bottom topography, and freshwater input set it apart from other areas of the North American west coast. The troughs and steep edges influence, and likely enhance, plankton and fish production. Strong tidal mixing in the narrow passes and channels enhances productivity around the periphery.

The overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components in the food web, as long as other species occur within the same functional group. However, trophic pathways to individual species may be more constrained; it is unknown which species may be critically sensitive to the reduction or elimination of other species. Existing data suggests that the trophic structure is largely controlled by "bottom-up" forcing.

The ecosystem receives a large biomass of migratory species: stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that enter PNCIMA when conditions are unusually warm. Migrants provide an input of energy and food, but also can export energy from the system, as in Pacific salmon's transfer of energy and nutrients from marine to terrestrial coastal ecosystems.

Habitat use for many large and/or commercial marine species found within PNCIMA is summarized, including significant nearshore and biologically productive pelagic habitats. Eleven appendices detail our current state of knowledge for the geology, meteorology and climate, physical and chemical oceanography, plankton, marine plants, invertebrates, groundfish, pelagic fishes, Pacific salmon, marine mammals and turtles, and sea birds in PNCIMA.

RÉSUMÉ

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

Le présent rapport donne un aperçu des écosystèmes biologiques et physiques de la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP). La ZGICNP est une zone étendue de gestion océanique parmi plusieurs créées afin que le ministère des Pêches et des Océans (MPO) puisse assurer la gestion écosystémique des activités humaines dans les zones marines. La ZGICNP est délimitée au nord par la frontière entre la Colombie-Britannique et l'Alaska, au sud par la péninsule Brooks (Nord-Ouest de l'île de Vancouver), l'île Quadra et l'inlet Bute, à l'ouest par la limite extérieure du talus continental et à l'est par les bassins hydrographiques côtiers.

La ZGICNP est caractérisée par des montagnes côtières abruptes et escarpées, un grand nombre d'îles extracôtières, une ligne de côte dominée par des rivages rocheux et quelques plages de sable et de gravier, des vallées et des fjords qui se prolongent sur le fond océanique, et une plate-forme continentale affouillée par les glaciers et présentant des dépressions transversales. L'océan Pacifique a un effet modérateur sur le climat et est responsable, de ce fait, des hivers chauds et humides et des étés frais de la côte Ouest. La ZGICNP est située dans une zone de transition entre une zone caractérisée principalement par la plongée du courant côtier de l'Alaska (au nord) et une zone caractérisée par la remontée du courant de Californie (au sud). La ZGICNP se distingue des autres zones de la côte ouest de l'Amérique du Nord par son bassin partiellement fermé, son fond à topographie variée et son apport en eau douce. Ses dépressions et ses bordures abruptes améliorent probablement la production de poissons et de plancton. Un mélange tidal important dans les passages et chenaux étroits entraîne une hausse de la productivité en périphérie.

La structure trophique globale de la région de la ZGICNP semble être relativement stable en cas de réduction ou d'élimination de composantes individuelles du réseau trophique, en autant que le ou les groupes fonctionnels touchés soient constitués d'autres espèces. Cependant, les voies trophiques menant à des espèces individuelles sont peut-être plus restreintes; les espèces qui pourraient être très vulnérables à la réduction ou à l'élimination d'autres espèces sont inconnues. Les données existantes suggèrent que la structure trophique est largement régulée par un mécanisme de forçage ascendant.

L'écosystème accueille une biomasse élevée d'espèces migratrices : il constitue la destination de certaines espèces, telles des baleines; il sert d'escale, notamment pour le saumon du Pacifique et des oiseaux marins migrateurs; il sert d'habitat pour des espèces, telles le zooplancton et des poissons pélagiques, qui y migrent lorsque les conditions sont plus chaudes que la normale. Les migrateurs importent et exportent de l'énergie et des ressources alimentaires de l'écosystème, comme dans le cas du saumon du Pacifique qui transfert de l'énergie et des éléments nutritifs des écosystèmes marins aux écosystèmes côtiers terrestres.

Le présent document comprend un sommaire de l'utilisation des habitats de la ZGICNP par de nombreuses espèces marines commerciales ou de grande taille, notamment des habitats pélagiques importants à productivité biologique élevée et situés près des côtes. Onze annexes présentent en détail nos connaissances actuelles relatives à la géologie, à la météorologie et au climat, à l'océanographie chimique et physique, au plancton, aux plantes marines, aux invertébrés, au poisson de fond, aux poissons pélagiques, au saumon, aux mammifères marins, aux tortues et aux oiseaux marins dans la ZGICNP.

PREFACE

This Ecosystem Overview is one of a several reports on the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is a Large Ocean Management Area (LOMA) created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada (DFO). This Ecosystem Overview covers the ecosystem status and trends for geological, oceanographic and biological systems in the LOMA. Other reports may include marine use analyses, ecologically and biologically sensitive areas, ecologically sensitive species, depleted species, degraded areas, ecosystem assessments, conclusions and recommendations.

Parts of this volume were based on an earlier report (Johannessen *et al.* 2005), which was drafted to compile background information for regional management of the north coast of British Columbia for DFO, and later expanded to include the central coast management area.

INTRODUCTION

PROJECT DEFINITION

Context and purpose

Canada's *Oceans Act* states that "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment." Implementation of integrated management planning is central to the new governance and ecosystem based management approach of the Oceans Action Plan (OAP). The OAP identified five priority Large Ocean Management Areas (LOMAs) across Canada for coordination of Integrated Management (IM) efforts. The Pacific North Coast Integrated Management Area (PNCIMA) is one; the others are the Eastern Scotian Shelf, Beaufort Sea, Gulf of St. Lawrence, and Placentia Bay/Grand Banks. Ecosystem Overview and Assessment Reports (EOARs) are one of the tools being used to develop ecosystem objectives for these LOMAs. Other reports being developed under the OAP include a Marine Use Analysis and a Socio-Economic Overview and Assessment Report.

The purpose of the PNCIMA Ecosystem Overview is to provide an overview of our current state of knowledge of the ecosystem(s) in PNCIMA. This Ecosystem Overview provides a knowledge base upon which impact assessments can be completed and recommendations provided for integrated management and sustainable use of the area (DFO Oceans Directorate 2005). As an overview, it provides a summary of the most relevant information and directs readers to publications with more comprehensive information. It is a science-based technical document, intended for use in ecosystem planning, and in preparation of later volumes of the EOAR.

The PNCIMA Ecosystem Overview was guided by a series of common EOAR principles: ecosystem focus, brevity and highlights, state of knowledge, scale integration of nested systems, ecologically significant boundaries, collaborative and team project, flexibility to regional constraints, multiple volumes, information management, and plain language (DFO Oceans Directorate 2005). It was produced with the best available information and state of knowledge.

Boundaries of the study area

PNCIMA's boundaries were determined primarily on ecological characteristics, and encompass approximately 88,000 sq km. It extends from the outer limit of the foot of the continental slope in the west, to the coastal watersheds in the east. The Canada-US border for Alaska is the northern boundary. The Brooks Peninsula on NW Vancouver Island and Quadra Island are encompassed in the southern boundary.

Report structure

This Ecosystem Overview is comprised of two summary chapters and 11 appendices. The first chapter is a description of what we know about how the ecosystem functions, the linkages, and interactions. It integrates the information detailed in the appendices and highlights key information gaps. Chapter 1 was reviewed and refined at a workshop in March 2006 held at the Institute of Oceans Sciences, in Sidney, BC.

The second chapter summarizes what is known about the use of habitat in PNCIMA by marine organisms for important life history functions, such as feeding, breeding, and migrating. The habitat map folio illustrates geographical areas for specific species or groups where those areas are large enough to be visible on a LOMA scale.

The appendices are excellent primers on their topics. They each provide important background details to understanding how and why PNCIMA ecosystems are structured and function the way they do. They also provide references to current literature for in-depth information on pertinent subjects.

CHAPTER 1: ECOSYSTEM DESCRIPTION

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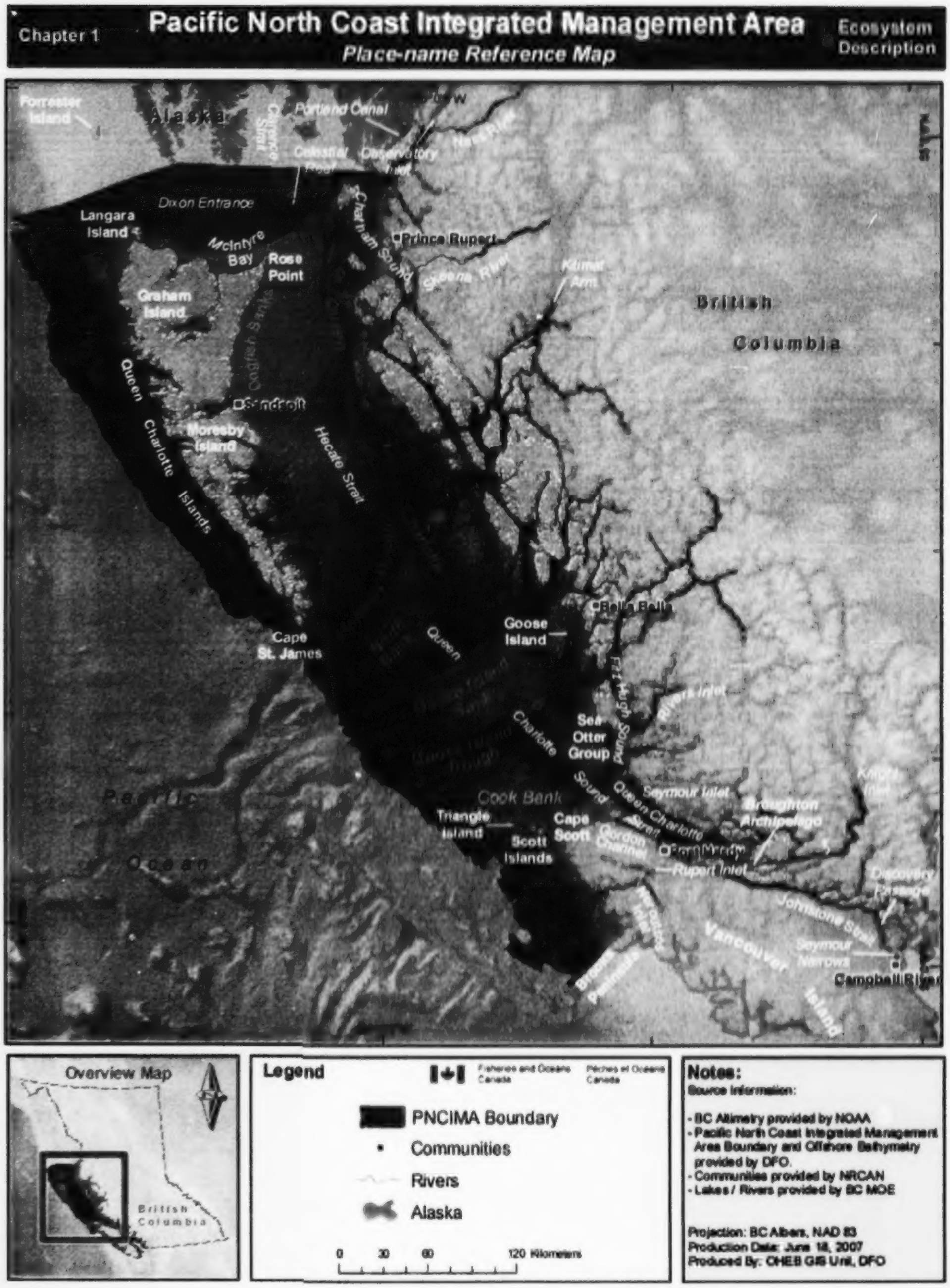
1.0 INTRODUCTION

This chapter integrates the information presented in the appendices, and provides the broad overview and synthesis of this material to understand "how the marine ecosystem(s) of the central and north BC coast (the Pacific North Coast Integrated Management Area; PNCIMA; Figure 1.0) works." It attempts to understand the structure and function of the system, and where there may be critical "control points" in space, time, or organisation (*e.g.,* trophic connections). An important additional objective is to identify critical unknowns and key information gaps to our understanding of how the ecosystem works.

This analysis includes nearshore and open water systems of the PNCIMA region. It does not include detailed consideration of inlet and fjord waters, largely because there are insufficient data from these areas. It also does not consider terrestrial systems nor detailed connections between terrestrial and marine environments.

We build our understanding of these marine ecosystems using four principal themes: (a) spatial patterns and processes; (b) food web interactions; (c) migratory species; and (d) temporal variability. We conclude with a summary and short discussion of key data gaps and uncertainties.


Chapter 1
Pacific North Coast Integrated Management Area
Place-name Reference Map
Ecosystem Description
Forrester Island
Alaska
Clarence Strait
Portland Canal
Celestial Reef
Observatory Inlet
Nass River
Dixon Entrance
Langara Island
McIntyre Bay
Rose Point
Chatham Sound
Prince Rupert
Skeena River
Kitimat Arm
Graham Island
Dogfish Banks
British Columbia
Queen Charlotte Islands
Sandspit
Moresby Island
Hecate Strait
Bella Bella
Goose Island
Cape St. James
Queen Charlotte Sound
Fitz Hugh Sound
Rivers Inlet
Sea Otter Group
Cook Bank
Seymour Inlet
Broughton Archipelago
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Scott Islands
Queen Charlotte Strait
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Port Hardy
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Johnstone Strait
Pacific Ocean
Vancouver Island
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Campbell River
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British Columbia
Legend
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PNCIMA Boundary
Communities
Rivers
Alaska
0
30
60
120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
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Figure 1.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 1.

1.1 GEOLOGICAL SETTING

The geology of the PNCIMA region steers and determines much of its physical and biological processes. The Pacific Coast today is the result of geological processes stretching back hundreds of millions of years. Over the largest time scale, the dominant process involved is plate tectonics, by which terranes from other parts of the world were accreted onto North America. Most of the bedrock of British Columbia was added to North America in this way. The slow but inexorable forces involved in this process also caused the tectonic uplift and buckling of the crust resulting in the mountain ranges of BC. Subsequent erosion of these mountains developed the sediment filled basins between these ranges.

The tectonic forces that have formed BC continue today and BC's offshore has a complex combination of plate boundaries including a subduction zone, spreading ridges, and transform faults. This results in a variety of earthquake environments that are capable of everything from frequent low magnitude earthquakes to giant megathrust earthquakes that can achieve magnitudes greater than 9 and have occurred roughly once every 300 years.

Over the last few million years, finer details have been chiselled into the tectonically developed bedrock features by the repeated advance and retreat of glaciers over the land. As subsequent glaciations largely erase the effects of the previous ones, most of the glacial features seen today are a result of the last glacial advance (between 10 and 30 thousand years ago). Many of the terrestrial glacial features have in turn been modified by fluvial erosion and deposition during postglacial time (the last 10,000 years), while the marine features have been subject to tides, currents, and littoral processes. Sedimentary input to the continental shelf has been very low since glacial retreat because the deep basins of the coastal fjords allow the settling of river-borne sediments. This results in a 'sediment starved' shelf where the older glacial deposits are constantly re-worked and produces a coastline dominated by rocky shores with few sand and gravel beaches.

The physical features of the coast also affect the freshwater input to the marine area. The PNCIMA area contains a variety of watershed forms resulting in different hydrologic profiles, though spring and summer meltwater runoff dominate the mainland watersheds which provide most of the freshwater input. This input and its timing are critical to phytoplankton blooms which form the base of the marine food chain. Global warming is already seen to be affecting the timing and volume of freshwater input in this area.

The PNCIMA area is also host to potentially significant petroleum-based resources. The Queen Charlotte Basin is one of four sedimentary basins found beneath Canada's Pacific continental shelf. Exploration from the 1960s to the 1980s suggests that this basin may hold significant reserves of oil and gas. Natural gas hydrates have also been found on southern portions of BC's continental slope. This potentially significant source of natural gas may also exist on the slope within the PNCIMA area. See Appendix A for more information on the geology of PNCIMA.

1.2 METEOROLOGY AND CLIMATE

British Colombia's coastal climate and weather conditions are a direct result of its position between the northeast Pacific Ocean and the Coast Mountains. Winds are dominated by the Aleutian Low Pressure system in winter and the North Pacific High in summer. This means that winter storms absorb great amounts of moisture as they track eastward toward the British Columbia coast. Much of this moisture falls as precipitation when it hits the Coast Mountains, making BC's coast the wettest place in Canada. The positions of the air pressure systems often cause winter storms to hit the central and north coast of BC more frequently than the southern coast. This results in the highest precipitation totals occurring within PNCIMA.

The ocean also moderates temperatures, with the winter storm winds transporting heat across the central Pacific and the milder northwest summer winds bringing relatively cooler air masses onto the coast. These air pressure systems and their winds also drive ocean circulation, which controls the source, and thus temperature, of water off the BC coast, which in turn affects coastal air temperatures.

Variations in climatic conditions strongly affect ecosystems. Most obvious is the seasonal variation that controls such things as the spring phytoplankton bloom, timing of peak stream flow, ocean wave intensity and ocean current strength and direction. However, the variation between years and decades for a given season is of great significance as these conditions can strongly affect the timing of ecosystem functions, which can be critical to the success of various biota. El Niño events, for example, transport warm waters and their biological communities northward to the BC coast, creating competition between indigenous and invasive organisms. There is an increasing focus in research on understanding how climate variability affects the ecosystem and whether that variability can be predicted.

PNCIMA is located in a transition zone between a northerly area dominated by the Alaska Current system and a southern area dominated by the California Current. The location of this transition zone varies depending on the relative dominance of these two systems. Shifts in this location are marked by periodic appearance of northern and southern species. See Appendix B for more information on the meteorology and climate of PNCIMA.

1.3 OCEANOGRAPHIC SETTING

PNCIMA forms the portion of BC coastal waters north of Campbell River and Brooks Peninsula and includes all salt and brackish waters in BC north of these two points as well as freshwater streams draining into these seas (Figure 1.0). In physical oceanographic terms, these waters form a transitional region north of the northern end of the California Current domain, and south of the southern end of the Alaska Current domain. Brooks Peninsula, on northwest Vancouver Island, is generally considered to be the dividing point between Alaska Coastal Current and California Current domains. Whereas the California Current is characterized by moderate to strong upwelling winds in summer, the Alaska Coastal Current is characterized by relaxation of winter downwelling in spring and summer rather than by upwelling winds. Where upwelling winds do occur in summer, generally in PNCIMA and SE Alaska, they are generally weak and persist only for a few months.

PNCIMA, in common with SE Alaska to the north, experiences extremely strong storms in autumn and winter with accompanying winds from the southeast and accumulations of metres of precipitation over autumn and winter (Figure 1.1). Coastal currents are forced by these winds to flow to the northwest alongshore, and can be considered the southern end of the Alaska Coastal Current. In parts of the three main basins on the shelf, Queen Charlotte Sound, Hecate Strait and Dixon Entrance, the currents are forced by the bathymetry to flow westward, or even upwind, but the overall surface flow is alongshore. The outer coast is wind and wave swept, and some inside regions, such as Dogfish Banks, experience sediment transport and shoreline erosion due to wind-forced waves. Inside channels and inlets are much more protected from waves and winds, and along many of these channels the trees extend right down to the high-tide line. Tidal currents range from the world's strongest to almost nil, with varying impact on the biota.

Inflow of major rivers is mainly into Chatham Sound and Observatory Inlet in the north, and into Fitz Hugh Sound on the central coast. Fresh waters flowing into Queen Charlotte Strait are considerably mixed with salt water by the time they reach this strait. Freshwater input from shorter rivers and directly onto the three main basins is considerable, and has to be accounted for in any balance of freshwater input. Tidal and wind-forced mixing of fresh water with sea water is hugely variable and determines many of the high primary production regions in PNCIMA, as noted later. See Appendix C for more information on the oceanography of PNCIMA.

These physical processes determine the ecosystem structure. Each of these physical inputs changes in nature and strength throughout PNCIMA, so that the ecosystem itself differs throughout this area. Despite these areal shifts, we present below a brief summary of the general features common to much of PNCIMA, with individual areas discussed later.

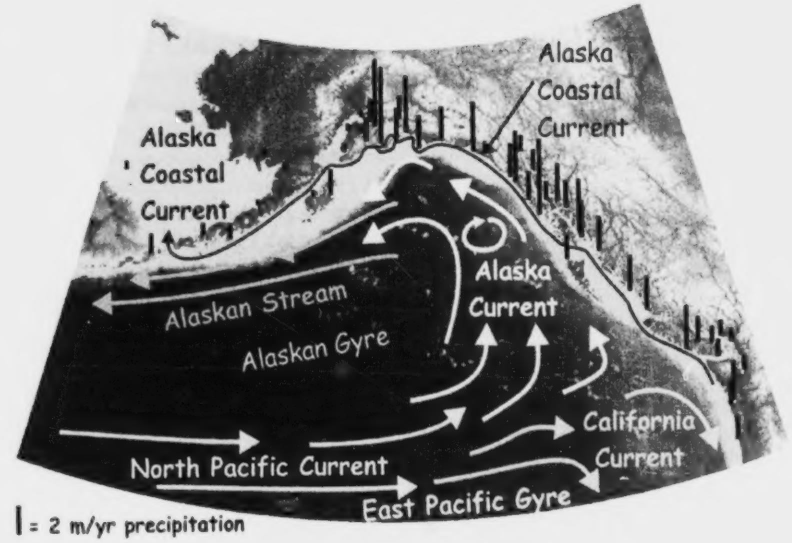


Figure 1.1 Surface circulation fields in the Gulf of Alaska (arrows) and average annual precipitation totals from coastal stations and the central gulf (black vertical bars) (adapted from Mundy and Olsson 2005 after; Baumgartner and Reichel 1975).

What regulates the biological productivity of this marine region?

The PNCIMA region is productive of plankton, fish and invertebrates. Ware and Thomson (2005) examined the primary productivity (growth rate of phytoplankton per year) of coastal NE Pacific and BC marine ecosystems, and concluded that resident fish yield was significantly correlated with the amount of primary production that was retained in these areas by physical processes. Using satellite observations of surface chlorophyll *a* concentrations for BC waters (Figure 1.2) from 1998 to 2005 as a proxy for the rate of primary production, and observations of zooplankton biomass and the total catch ("yield") of resident fish, they calculated that a significant linear relationship existed between mean average chlorophyll *a* concentration (in mg m^{-3}) and average annual resident fish yield (in metric tons km^{-2}):

$$\text{Long-term Fish Yield} = 0.08 + 0.437*[\text{chl.}a] \qquad (r^2 = 0.76, P = 0.015) \qquad (1)$$

This equation suggests that a sustained doubling of the annual average chlorophyll *a* concentration would lead to an approximate doubling of the annual yield (catch) of resident fish species. Resident fish species were defined to exclude species such as Pacific hake, Pacific sardine, and pink, chum, sockeye, and coho salmon, which are believed to reside or pass through the PNCIMA marine ecosystem for only short periods of their life.

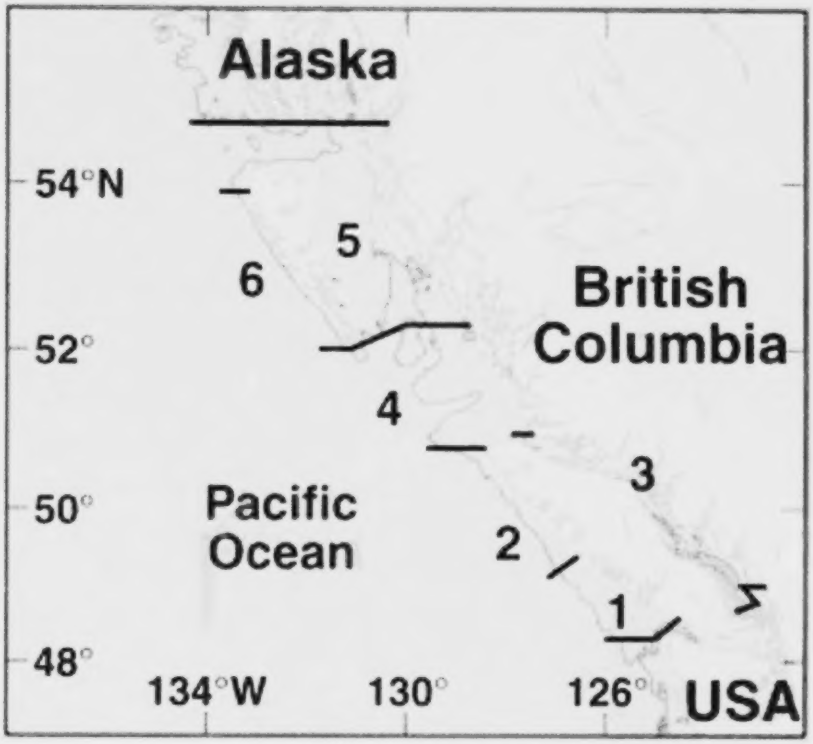


Figure 1.2 Regions of the BC coast examined by Ware and Thomson (2005) for comparisons of primary production and resulting catches of resident fish. 1: southern Vancouver Island shelf; 2: northern Vancouver Island shelf; 3: Strait of Georgia; 4: Queen Charlotte Sound; 5: Hecate Strait; 6: west coast Queen Charlotte Islands (from Ware and Thomson 2005).

For the coastal waters of BC, the relationship of chlorophyll to zooplankton (in mg dry weight m^{-3}) was not linear, whereas that between zooplankton and the long-term catch of resident fish was linear (Figure 1.3):

$$\text{Zooplankton} = 46.57 * [\text{chl.}a]\ 0.488 \qquad (r^2 = 0.85) \qquad (2)$$

$$\text{Long-term fish yield} = 0.055 * \text{Zooplankton} - 1.98 \qquad (r^2 = 0.79) \qquad (3)$$

This suggests that the amount of zooplankton in BC waters, and the subsequent amount of fish, can be estimated (on a long-term annual basis) from the amount of phytoplankton that is produced each year.

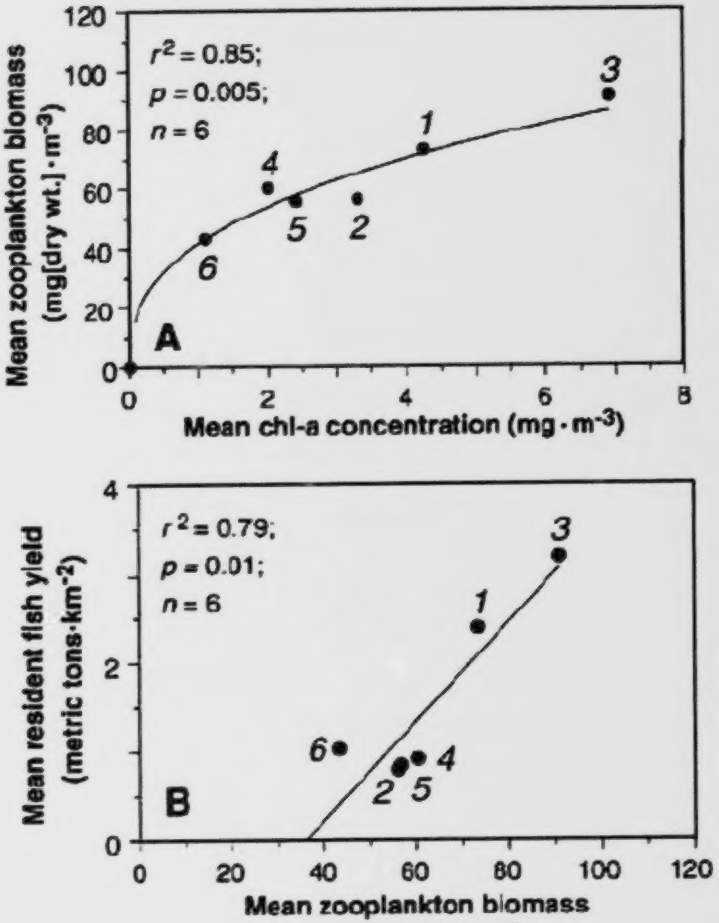


Figure 1.3 Relationships of chlorophyll *a* biomass to zooplankton biomass (top) and between mean zooplankton biomass and mean yield (catches) of resident fish populations (bottom) for the six regions of the British Columbia coast (see Figure 1.2) identified by Ware and Thomson (2005).

When compared among eight geographic regions from southern California to Kodiak, Alaska (Figure 1.4), Ware and Thomson (2005) found that the "Charlotte" region (equivalent to the PNCIMA shelf region) ranked sixth in terms of mean annual chlorophyll *a* biomass per unit surface area (with the region west of Vancouver Island ranking first). However, this "Charlotte" region ranked third in terms of its long-term annual fish yield per unit surface area, after the Vancouver Island and Columbia regions (Table 1.0). Ware and Thomson (2005) suggested that the higher fish yield per unit of chlorophyll in this "Charlotte" region is because more of this chlorophyll is retained on the continental shelf as a result of reduced upwelling compared with regions further south due to the presence of the Queen Charlotte Islands that form a barrier to movement of water into the deep ocean.

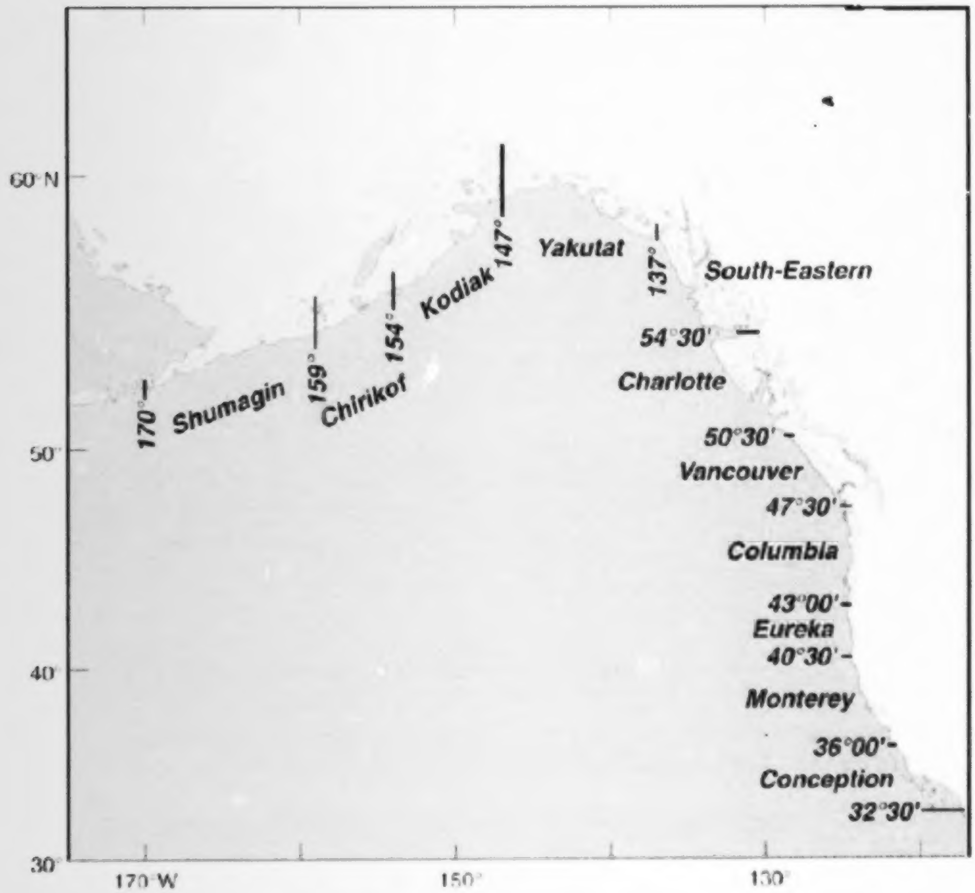

60°N
50°
40°
30°
170°W
150°
130°
170°
Shumagin
159°
Chirikof
154°
Kodiak
147°
Yakutat
137°
South-Eastern
54°30'
Charlotte
50°30'
Vancouver
47°30'
Columbia
43°00'
Eureka
40°30'
Monterey
36°00'
Conception
32°30'

Figure 1.4 Regions of the coastal NE Pacific considered by Ware and Thomson (2005) for relationships between chlorophyll *a* biomass and long-term annual fishery yield of resident fish stocks (from Ware and Thomson 2005).

Table 1.0 Mean annual chlorophyll *a* concentrations (with temporal coefficients of variation for the period 1998-2003 in parentheses) and long-term annual fishery yields of resident species for various coastal regions of the NE Pacific (see Figure 1.2 and Figure 1.4)(from Ware and Thomson 2005).

Region	**Surface area (km^2)**	**Chl-*a* ($mg\ m^{-3}$)**	**Resident fish yield ($t\ km^{-2}$)**
Conception	60,046	1.38 (0.57)	0.06
Monterey	41,613	2.29 (0.54)	0.45
Eureka	18,692	2.20 (0.86)	0.66
Columbia	36,573	3.24 (0.68)	0.88
Vancouver	34,688	5.15 (0.66)	1.97
Charlotte	82,769	2.16 (0.69)	0.79
Southeast Alaska	43,342	2.79 (0.80)	0.60
Yakutat	76,430	1.57 (0.63)	0.27
British Columbia			
S. Vancouver Island (1)	11,312	4.25 (0.70)	2.39
N. Vancouver Island (2)	10,099	3.30 (0.71)	0.85
Strait of Georgia (3)	8,803	6.92 (0.57)	3.19
Q.C. Sound (4)	31, 408	2.00 (0.71)	0.92
Hecate Strait (5)	44,158	2.41 (0.68)	0.80
West coast Q.C. Islands (6)	7,203	1.10 (0.69)	1.03

When analysed at the finer spatial scale of six BC coastal regions (Figure 1.2), Ware and Thomson (2005) found that on a per unit surface area basis the three northern regions (Queen Charlotte Sound, Hecate Strait, west coast Queen Charlotte Islands) had below the average (3.34 ± 2.08 mg m^{-3}) chlorophyll *a* mean annual biomass for these six regions, and below the average (1.53 ± 1.01 t km^{-2}) long-term fish yield (Table 1.0). Within BC, therefore, ocean productivity is higher in southern BC than in the north, although the data are skewed by the very high chlorophyll *a* concentrations and fish yields on the southwestern continental shelf of Vancouver Island and in the Strait of Georgia.

Overall, these analyses of Ware and Thomson (2005) suggest that the PNCIMA region of the BC coast has moderate annual phytoplankton biomass, but high long-term fishery yields of resident fish populations, compared to other regions from southern California to Alaska. These analyses also indicate that, at least on large spatial scales, zooplankton biomass and higher fishery yields of commercial resident fish populations are directly related to the amount of mean annual primary production and resulting chlorophyll *a* biomass. Therefore, the (partial) answer to the question "What regulates the biological productivity of this region" is phytoplankton production and retention, so that any sustained process or event which changes phytoplankton production substantially will eventually have measurable effects on fish production in these systems. The obvious next question, however, is "What regulates phytoplankton production in this region?"

1.4 SPATIAL AND SEASONAL PATTERNS

We have selected eight sub-regions of PNCIMA based on physical and phytoplankton-related processes that are common to each of these sub-regions. Relevant to this discussion are three figures from Appendix D: Plankton (Figure 1.5). These images show the spatial and seasonal variability of phytoplankton concentrations at ocean surface, as inferred from spectral colour data collected by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor on the American Orbcom satellite. Individual regions in these images are discussed below as they relate to the physical forces of PNCIMA: winds, waves, tides, fresh water, heating and bathymetry.

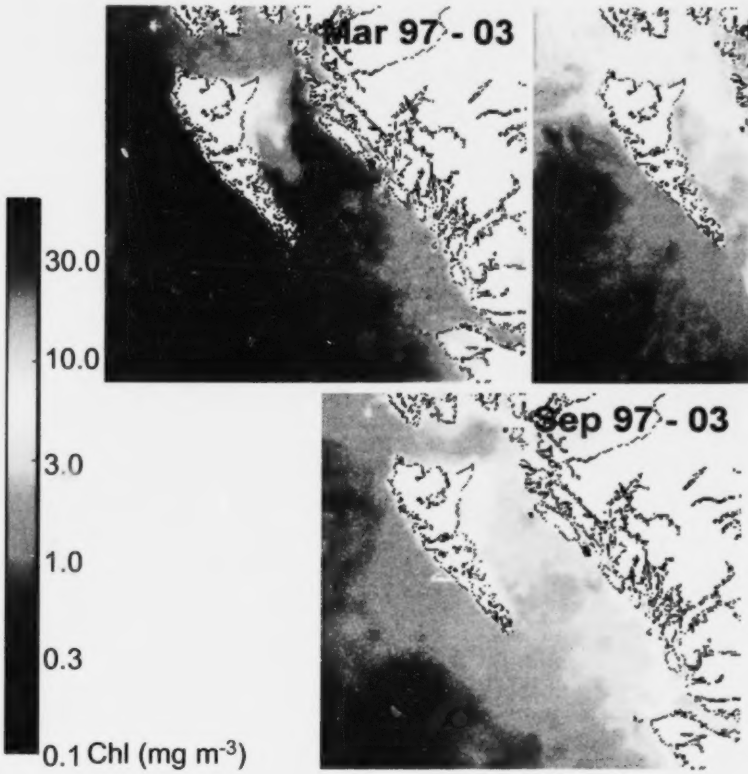


Figure 1.5 Aggregated monthly averaged satellite-derived chlorophyll data from 1997 to 2003 for March, May and September. Data reveal ocean-surface phytoplankton hotspots, and the fact that the shelf is quite productive (>1 mg m^{-3}) from March through to September (A. Peña, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2006).

An interesting seasonal cycle of phytoplankton concentrations in surface waters was detected by the SeaWiFS satellite. Spring phytoplankton bloom first arrives at NE Hecate Strait in March (as described later), then in eastern Hecate Strait and Queen

Charlotte Sound in May, with low plankton concentrations along western Hecate Strait in May. This May pattern partially reverses in September, when the western side of Hecate Strait holds higher concentrations of phytoplankton that the eastern side. We speculate these high spring levels are associated with relaxation of winter downwelling and mixing of outflowing fresh waters with high-nutrient sub-surface waters. By September, outflow of fresh water is at a seasonal minimum, and both downwelling relaxation and upwelling have turned off, dropping productivity along the eastern shore. However, shallow bottom depths along the west side of Hecate Strait might allow the early autumn storms to mix high-nutrient bottom waters to the surface.

The eight sub-regions are:

(a) Campbell River to Port Hardy,

(b) Queen Charlotte Strait to Brooks Peninsula,

(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance,

(d) Cape St. James,

(e) Western Hecate Strait,

(f) Dixon Entrance,

(g) West Coast Queen Charlotte Islands,

(h) Inlets.

(a) Campbell River to Port Hardy

This region comprises the channels of Seymour Narrows, Discovery Passage, Johnstone Strait and the eastern end of Queen Charlotte Strait, as illustrated in Figure 1.0. Tidal mixing gives these channels their unique status. These waters experience extreme tidal mixing, with Seymour Narrows likely holding the world record for most tidal mixing and dissipation in a single narrow channel. Waters are well mixed top to bottom in several hundred metres depth in many portions of these straits, yet these channels support an estuarine circulation. In Johnstone Strait this estuarine circulation is evident in the mean velocity and water properties structure. There is a mean seaward (westward) upper layer flow of about 0.2 m s^{-1}, strongest on the mainland side due to the Coriolis force, while the mean lower layer flow is landward (eastward) at about 0.1 m s^{-1}, strongest on the Vancouver Island side (Thomson 1981). As noted above in Section 1.0, these channels and the inlets receive relatively little attention in our report due to lack of ecological data.

They support excellent sports fishing for salmon, especially near Campbell River. This fishing is perhaps due to the containment of salmon in the narrow channels on their return to spawn. Many to most juvenile salmon from the Fraser River transit these channels on their outbound migration.

Because these channels are so well mixed, the primary productivity is expected to be relatively low. Phytoplankton in very turbulent waters spend too little time at surface to support strong blooms. This relatively low productivity is expected to permit the waters that are nutrient enriched by tidal mixing to exit this region into Queen Charlotte Strait with relatively high nutrient concentrations at surface.

Some recent studies have focussed on the Broughton Archipelago, where sea lice impact on pink salmon has been an issue that has stimulated significant research into the relative contribution of natural and fish farm sources of sea lice. These efforts and recommendations for future research are noted by Pennell and Ackerman (2006). This topic should provide a cautionary note on the difficulty in managing natural and aquaculture stocks of fish in the same region. After several years of research the scientific community has not reached consensus on the impact of sea lice from fish farms on the wild stocks of pink salmon (Pennell and Ackerman 2006). We refer readers to the ongoing research efforts in the Broughton Archipelago rather than attempt to provide another summary here.

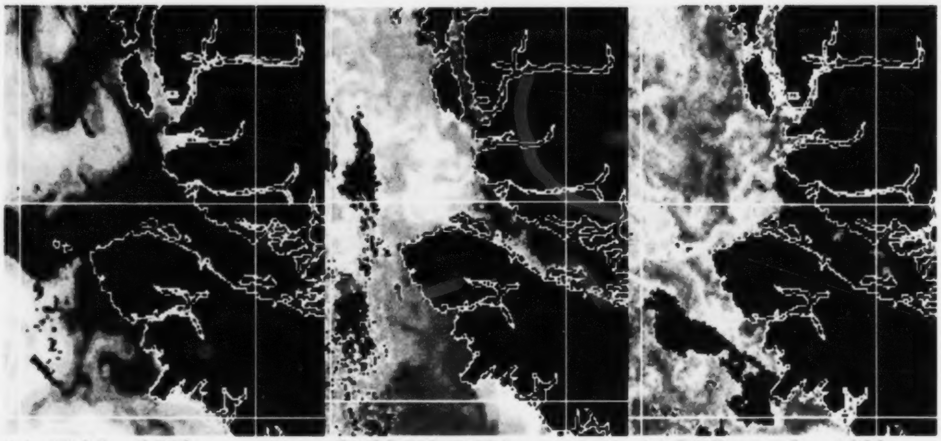
(b) Queen Charlotte Strait to Brooks Peninsula

These waters follow the northern shore of Vancouver Island, starting at the eastern end of Queen Charlotte Strait, through Gordon Channel, Cook Bank, Scott Islands, and finally along the west coast of Vancouver Island south to Brooks Peninsula (Figure 1.0). This region is marked by relatively high phytoplankton concentrations in May and September, as revealed by SeaWiFS imagery in Figure 1.5, which can be attributed to a combination of winds, tides, and nutrient input from inlets and channels. The individual physical features are:

- well mixed outflow in a thick surface layer from Johnstone Strait and Broughton Strait,
- fresher outflow in a shallow surface layer from Fitz Hugh Sound and Smith Sound,
- strong SE winds in winter and weaker NW winds in summer,
- tidal mixing at and near the Sea Otter Group of islands, as well as near the reefs and small islands between the Sea Otter Group and the mainland,
- tidal mixing over Cook Bank and near the Scott Islands,
- offshore-directed cold plumes from the Scott Islands and Brooks Peninsula in summer.

Compared to other PNCIMA regions, this highly productive region has lower retention of surface waters and their biota due to the westward flows over Cook Bank past Scott Islands in spring and summer when winds blow from the north.

Figure 1.6 presents satellite images of surface water temperature of this region in spring and summer.



(a) 19 May 2002 (b) 23 July 1994 (c) 21 September 1993

Figure 1.6 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Centre image is from the same day presented in Figure 1.7.

These three images of Figure 1.6 each show cooler water in Queen Charlotte Strait, likely due to cold outflow from channels to the SE. Nutrient measurements in summer reveal these waters of Queen Charlotte Strait to be rich in nitrate, with levels over 10 μM being among the highest observed in PNCIMA (Appendix C, Figure C.23). Comparison of nitrate and temperature images shows the highest nutrients in the coldest waters, supporting the concept that deep cold waters brought to the surface have highest nitrate levels. By contrast, the outflow from Fitz Hugh Sound and Smith Inlet is often warmer than surrounding waters, perhaps due to the presence of sediments to absorb sunlight, and to the shallow depth of this surface freshwater plume. Chlorophyll images of Figure 1.5 suggest highest concentration of phytoplankton in May are in the portion of the outflow from Fitz Hugh Sound closest to the cold waters from Queen Charlotte Strait. We can speculate these are where these two water masses mix, providing maximum surface nutrients and thinnest surface layers, both leading to high phytoplankton growth rates. The strong tidal flows and tidal mixing near the Scott Islands likely provide additional input of nutrients to surface waters to support the seabird colonies on the Scott Islands.

In summer we often observe westward flowing plumes of coastal (cool) waters into the Pacific, from regions at and between Brooks Peninsula and the Scott Islands. These are expected to have been set up by NW winds piling up water along the north shore of Vancouver Island. Current meters set on Cook Bank in the 1980s showed accelerating westward flow when winds blew from the NW, and accelerating eastward flow with winds from the SE, providing support for the causes of these plumes. Surface drifters deployed in spring and summer in Queen Charlotte Sound in the 1990s drifted to the south and southwest during the prevailing winds from the northwest. Many of these drifters departed Queen Charlotte Sound to the southwest, or grounded on Vancouver Island (Crawford *et al.* 1999). However, not one of the drifters that departed Queen Charlotte Sound grounded on Vancouver Island south of Brooks Peninsula, or even came close to shore here. This behaviour suggests little transport of free-floating life south from PNCIMA to shores south of PNCIMA along the west coast of Vancouver Island.

(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance

Storm winds of winter push flow alongshore at all depths along this region, and contain much of the fresh water up against the eastern islands (Figure 1.0). Return flow to the south is found at depth along the western sides of Hecate Strait, and is considered to be the source waters for Haida Eddies that form off SW Moresby Island in winter.

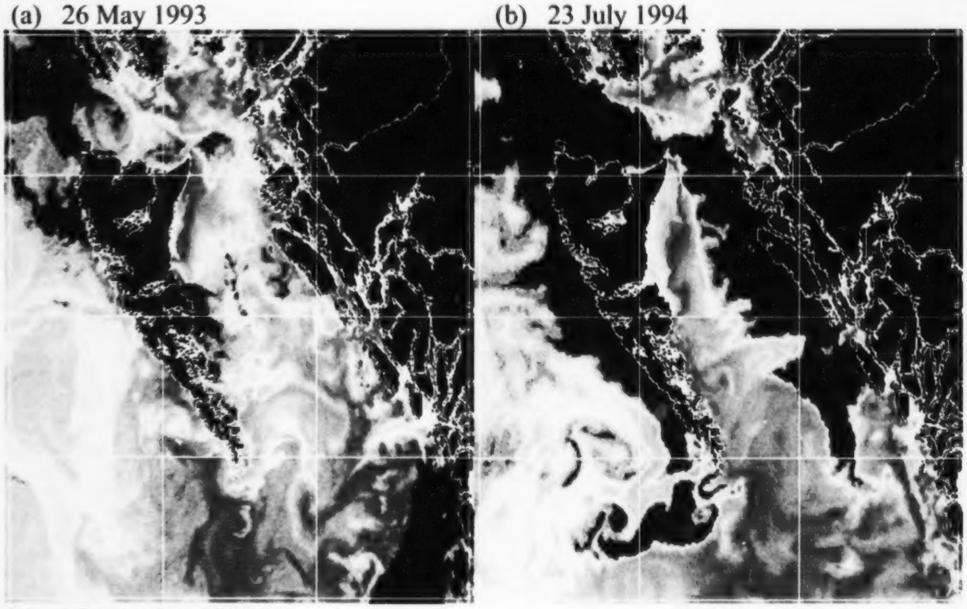
Bottom waters of the troughs of this system are warmest in winter, and may account for the winter spawning of many species of fish: Pacific cod for example. However, other factors such as food availability in spring can also be important. It is speculated that an eddy forms over North Bank in winter, and this eddy allows many of the ichthyoplankton of Pacific cod and other species to remain in Hecate Strait-Queen Charlotte Sound through the winter. This eddy would redirect to the north a portion of the return southward flow along the west side of Hecate Strait. Winter winds mix nutrient-rich water up from the bottom or near bottom, and when combined with Ekman downwelling, account for ample nutrient supply to all depths here in winter.

The high phytoplankton concentrations, noted above to lie between Fitz Hugh Sound and Cook Bank in May, are matched only by the high levels in Chatham Sound. These two regions receive the strongest outflow of fresh waters in spring, so we expect this outflow is linked to high chlorophyll concentrations. The Skeena River plume in Chatham Sound might mix with nutrient-rich waters below to produce the shallow, nutrient-rich surface layer needed for phytoplankton growth.

The Chatham Sound region of highest phytoplankton concentrations in May actually extends into northern Hecate Strait. This region receives Skeena Plume waters after they mix with deeper waters in Brown Passage and Edye Pass. Such mixing might provide the nutrient-rich, shallow surface layer to stimulate productivity. However, many other processes could enrich these waters, and we do not wish to speculate further.

The central coast between Fitz Hugh and Chatham sounds (Figure 1.0) receives lesser flows of freshet waters, and the May chlorophyll images of Figure 1.5 reveal lower concentrations of phytoplankton in surface waters than in Chatham Sound and near Fitz Hugh Sound. Deeper colder water progressively penetrates into Queen Charlotte Sound and Hecate Strait troughs in spring through late summer, attributed first to relaxation of winter downwelling, then to some extent in mid-summer to upwelling winds blowing from the north along these straits. These deep waters are nutrient-rich, providing food for all bottom life including sponge reefs.

Along this eastern side of the region during spring and summer, higher surface concentrations of chlorophyll are maintained by an estuarine-like circulation effect driven by freshwater runoff from the coastal mountains and inlets (F. Whitney, DFO, Institute of Ocean Sciences, Sidney, BC, pers. comm., 2006). In this process, the summer relaxation of the winter downwelling winds and/or weak summer upwelling brings the deep nutrient-rich waters close to the surface where it is available for phytoplankton growth by entrainment into the brackish surface flows over the saltier water. Energy for entrainment can be provided by tides or winds. These colder waters are clearly present in Figures 1.7b and 1.7c.



(a) 26 May 1993

(b) 23 July 1994

(c) 4 September 1993

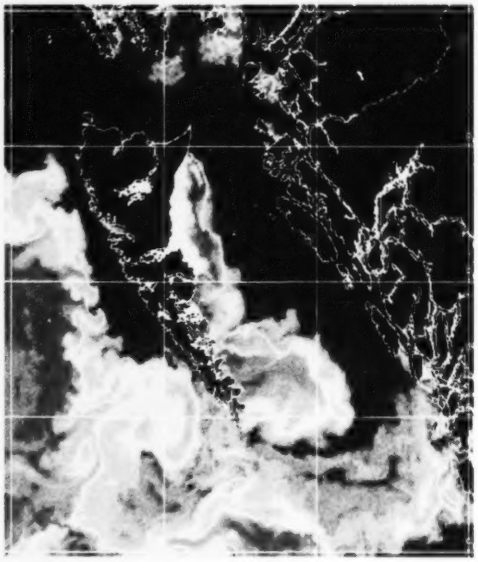


Figure 1.7 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Image (b) is from the same day presented in Figure 1.6, with slightly different colour scale.

Phytoplankton concentrations along this central eastern coast decrease through summer, despite the occurrence of strongest upwelling winds in July. Therefore it is not a combination of upwelling winds and freshet that account for the high phytoplankton concentrations in May in surface waters of this eastern coast. More likely it is the rich nutrients stirred to surface in winter that trigger this spring bloom, as occurs elsewhere in mid-latitude oceans. In this case, the rich phytoplankton concentrations seen by satellite in Chatham and outside Fitz Hugh sounds are attributed mainly to the shallow surface layer in the fresh water plumes.

(d) Cape St. James

Waters near Cape St. James deserve their own category. Flow at this cape exerts huge impact on primary and secondary productivity of surrounding waters, yet this impact is not observed in SeaWiFS imagery. Several factors are at play here:

- deep waters with very strong tidal mixing,
- persistent outflow from Hecate Strait past this cape,
- formation of Haida Eddies by winter outflow past this cape,
- close proximity of deep inflow to Hecate Strait.

Studies in the 1990s revealed strong and persistent outflow of surface water from southern Hecate Strait into the Pacific Ocean. This flow is confirmed to within 15 km of Cape St. James. Therefore any flow from Hecate Strait to the open Pacific Ocean passes close by this region. Once there, it mixes thoroughly with surrounding oceanic waters, forming cold surface plumes visible in satellite imagery for up to 120 km away from the cape. These plumes occasionally re-circulate at surface into Queen Charlotte Sound, as noted in drifter tracks (Crawford *et al.* 1995) and also in satellite imagery in Figure 1.7a (inflow appears as a relatively warm plume headed to the NE). This recirculation might be even stronger in sub-surface flows. The deep channel of Moresby Trough is close to this cape, so inflowing waters will likely entrain some of the waters mixed at the cape. Finally, the strong winter outflow from Haida Eddies can hold as much as the entire water volume of Queen Charlotte Sound and Hecate Strait combined. Fisheries and Oceans Canada (DFO) studies in the oceanic NE Pacific have found coastal species of zooplankton and nutrients in these eddies, as well as much of the winter supply of heat and fresh waters entering these two basins. Clearly Haida Eddies transport coastal waters and their properties out to 1000 km or more from this cape.

Given this high mixing rate, the lack of high chlorophyll concentrations observed by SeaWiFS need some explanation. We speculate on relevant factors here. Despite the strong mixing at this cape, there is no supply of fresh water to keep this mixed water at the surface, so much of the mixed water will sink below the euphotic zone. This lack of chlorophyll here underlines the need for fresh water in estuaries and coastal regions to support high productivity in mixed waters. Secondly, nutrient-rich water mixed to the surface here will advect away from the cape with two days and enter another domain. So phytoplankton spend too little time in this region and near the surface for primary productivity to develop.

(e) Western Hecate Strait

This is another unique region of PNCIMA. In an area of deep rocky fjords the shallow banks of this region offer unique ecology. For example, a rich supply of sediments is provided to NW Dogfish Banks by the eroding adjacent shores of eastern Graham Island. This shoreline erodes more rapidly than any other in Canada. Interestingly, second highest tides of BC are found here (tides at the head of Portland Canal are highest), and strongest wave-generated ocean mixing. Indeed, the combination of tidal mixing and wave-forced mixing keeps portions of this bank well mixed at almost all times. Lack of deeper cool water in summer, and deeper warmer water in winter assures this region is coldest in winter and warmest in summer of all PNCIMA regions on the continental shelf.

Biologically, this region is usually linked to McIntyre Bay in SE Dixon Entrance, due to the high concentrations of Dungeness crab in these two regions. McIntyre Bay is accreting, perhaps as the recipient of Dogfish Banks sediments or possibly locally derived sediments. We speculate that the presence of Dungeness crab are more likely due to the broad shallow banks than to any other factor. Their abundances go up and down over the years, with little predictability.

SeaWiFS imagery of Figure 1.5 shows that Dogfish Banks and the nearby regions of McIntyre Bay are the first to experience plankton blooms in spring, with strong growth in March. Although this season also experiences high sediment loads in surface waters here, the satellites are able to detect the unique spectral levels of plankton in reflected daylight, and these signatures indicate high levels of chlorophyll here.

This early development of chlorophyll biomass is predictable from knowledge of nutrient dynamics and the potential depth of vertical mixing. Higher chlorophyll concentrations over Dogfish Banks in northwest Hecate Strait occur because the depth of vertical mixing is limited by the shallow depths of the bottom, whereas in deeper areas winds are able to mix the water column, and its constituent phytoplankton cells, below the critical depth for phytoplankton blooms to occur (Perry and Dilke 1986). By May, the nutrients on the shallow bank are exhausted and phytoplankton concentrations decline. In addition, there appears to be little exchange of waters between Dogfish Banks and deeper regions to enable import of nutrients (Crawford *et al.* 1998). Deep areas have a greater store of nutrients, and in many cases import nutrients and are able to maintain higher phytoplankton concentrations later into the spring, especially along the frontal regions in this area (Perry *et al.* 1983).

Waters along the southwest side of Hecate Strait are deeper than on Dogfish Banks and only in September do the SeaWiFS images reveal more than average concentrations of phytoplankton. Lack of plankton in May might be due to lack of freshwater plumes to form shallow, nutrient-rich surface layers, since little runoff flows from the Charlottes compared to other shores.

(f) Dixon Entrance

In a region of north-south channels this strait clearly offers a unique aspect to PNCIMA. It is the deepest of the three basins, and its deep central axis extends into Clarence Strait and US waters to the north. Deep flows here are directed eastward year-round. But its most unique feature is the Rose Spit Eddy north of Rose Point at the NE corner of Graham Island. This feature was noted in early water property surveys of the region (Crean 1967), and also in the Hecate hydraulic model built in the 1960s at Pacific Biological Station (PBS) in Nanaimo. Several oceanic studies of the 1980s and 1990s observed this eddy in tracks of near-surface drifters and in dynamic height anomalies in both summer and winter. Finally, satellite images of sea surface temperature offer evidence for its existence. These numerous studies are offered as evidence, because theoretical and numerical studies offer only weak evidence for its presence. In physical oceanographic terms, this strait is sufficiently wide that the estuarine flow here will be out on the north side and in on the south side, both at surface, rather than out on the surface and in at subsurface depths as found in more narrow channels. With the Skeena River and Nass River plumes flowing usually to the north of Chatham Sound, and these outward and inward estuarine flows on the north and south sides of Dixon Entrance respectively, only a southward flow in the west is needed to complete the eddy. Forcing for such a flow is provided by NE winds in summer.

The eddy leaks considerable water, with outflow directed to the NW past Forrester Island or to the SW past Langara Island. Generally only one or the other of these routes is taken at any one time, with some evidence of influence of the wind on choice of routes (Crawford and Greisman 1987).

A second interesting feature is the strong internal semi-diurnal (twice-daily) tidal currents in Dixon Entrance, up to 60 cm s^{-1}, and much stronger than expected for the range of tides present. Internal tides are due to up-and-down motion of sub-surface waters in this basin, and are expected to be set up along the narrow ridge that runs through Celestial Reef in eastern Dixon Entrance.

(g) West Coast Queen Charlotte Islands

Here we have yet another unique region of PNCIMA, also unique to the North American West Coast. The continental shelf west of Moresby Island is the narrowest of British Columbia, with the least freshwater input. The shelf west of Graham Island is somewhat wider, with somewhat more freshwater input. Both coasts experience extreme pounding by winter waves. So it is not surprising that fisheries here are mainly for deep-water species along the continental slope. The remoteness of this region and numerous small islands allow seabird colonies to thrive.

(h) Inlets

As noted earlier, this overview does not include detailed consideration of inlet and fjord waters, largely because there is insufficient data in these areas and each inlet requires its own study. The inlets in PNCIMA are numerous, and require more attention for environmental assessment. Many inlets (Knight, Rupert, Neroutsos, Observatory, Seymour, and Rivers inlets, Alice and Kitimat arms, and Fitz Hugh Sound) have been studied for assessment of specific industries or fisheries issues.

These inlets are deep with slow tidal currents, and considerable freshwater input. As a result, the outflow plumes of fresh water are shallow, often 1-5 metres deep, and often form shallow outflows into Hecate Strait, Queen Charlotte Sound and Dixon Entrance, as well as the outer coast. Knight Inlet in the south has been the subject of many detailed studies of tidal flow and mixing at its sill, and this information is available for application to other inlets. However, mixing and biological processes in each fjord depend on the depth, shape and position of the sills, as well as prevailing wind directions, complex geography of the inlet, and freshwater input. Each inlet can be considered unique.

A case of interest is the abrupt decline of Rivers Inlet salmon populations in the late 1990s. Although there have been numerous studies of this region since then, the factors influencing this run are not well known. McKinnell *et al.* (2001) provided evidence that the collapse of some stocks within PNCIMA was due unknown events that influenced marine survival (see Appendix I: Salmon). This example, together with the continuing conflict over sea lice and fish farms in Broughton Archipelago, should warn us of the difficulties in assigning anthropogenic and natural causes of ecosystem change in PNCIMA before, during and even after human impact on this area.

1.4.1 Linkages to Zooplankton and Fish

Zooplankton are known to aggregate on bathymetric edges likely as a result of convergent processes but also partially in response to higher phytoplankton concentrations. There have been few direct observations of zooplankton distributions in PNCIMA, certainly in comparison to southwest Vancouver Island. However, as inferred from distribution patterns observed elsewhere and a limited amount of field data, euphausiid concentrations should be highest on the continental slope and along the margins of the deep troughs in Queen Charlotte Sound (see Appendix D: Plankton).

Within PNCIMA, groundfish are most abundant in Goose Island Trough, near Cape St. James, and at the southeast end of Dixon Entrance. Other significant aggregations are seen along bathymetric edges around Goose Island and Middle banks (North Bank) as well as the northern edge of Moresby Trough (Figure 1.8). This distribution pattern is supported by results of groundfish bottom trawl surveys (A. Sinclair, unpublished data). The DFO trawl survey program has recently been expanded to include Queen Charlotte Sound and to provide greater coverage of Dixon Entrance and Hecate Strait. While the dataset is much less extensive than that from the commercial fishery, the surveys provide information from areas not normally fished.

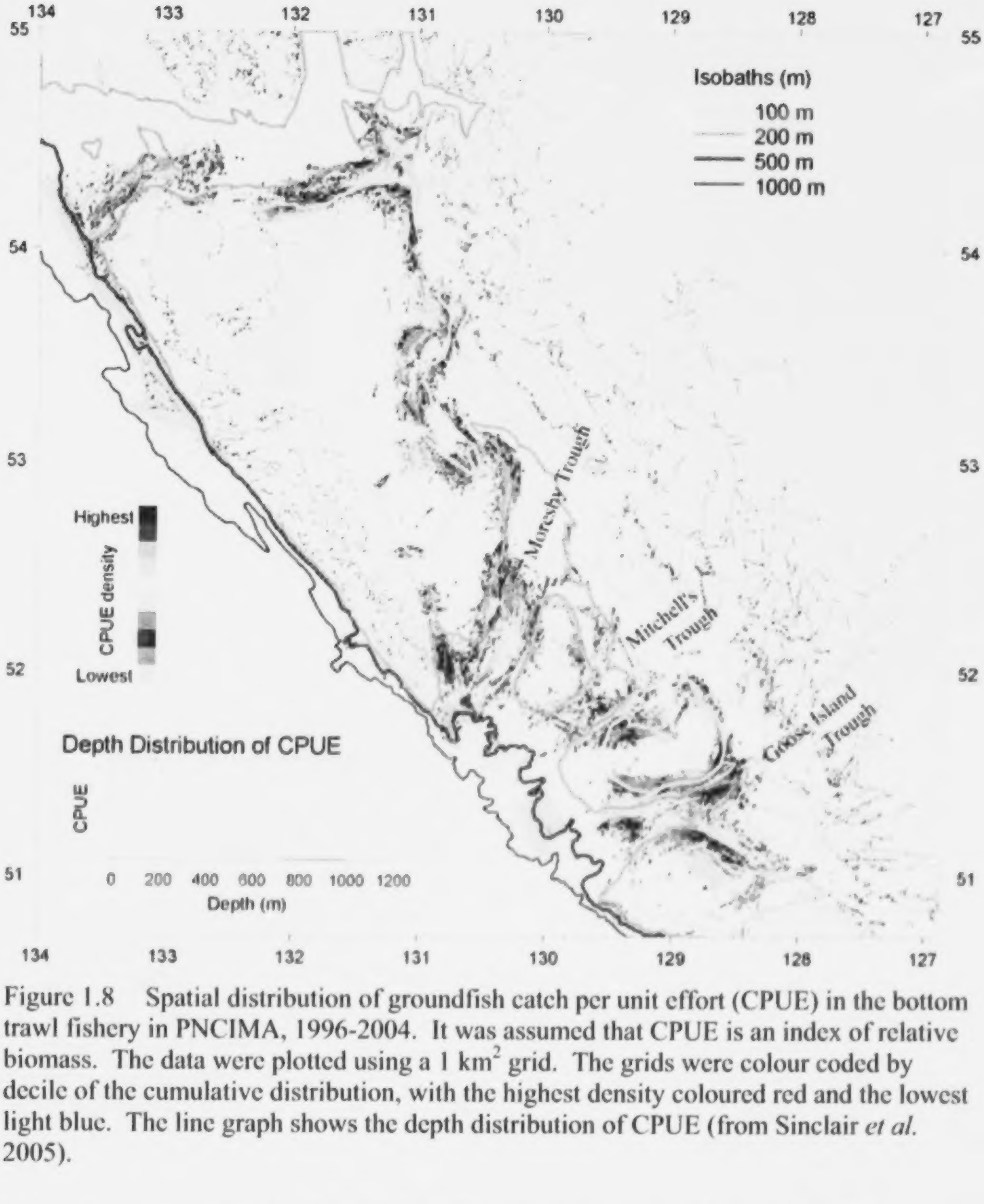

Isobaths (m)
100 m
200 m
500 m
1000 m
Moresby Trough
Mitchell's Trough
Goose Island Trough
Highest
CPUE density
Lowest
Depth Distribution of CPUE
CPUE
0 200 400 600 800 1000 1200
Depth (m)
134
133
132
131
130
129
128
127
55
54
53
52
51

Figure 1.8 Spatial distribution of groundfish catch per unit effort (CPUE) in the bottom trawl fishery in PNCIMA, 1996-2004. It was assumed that CPUE is an index of relative biomass. The data were plotted using a 1 km^2 grid. The grids were colour coded by decile of the cumulative distribution, with the highest density coloured red and the lowest light blue. The line graph shows the depth distribution of CPUE (from Sinclair *et al.* 2005).

The main concentrations in Goose Island Trough and southeast Dixon Entrance are adjacent to the areas of highest phytoplankton concentrations. The combinations of estuarine flows in these two areas and the existence of bi-directional flows provide the mechanisms for enrichment from primary production, concentration of food supply, and retention of particles in these areas to explain the high abundance of fish there. In contrast, the central and southern portions of Hecate Strait at depths less than 100 m have lower fish biomass, are further away from an abundant source of primary production, and have relatively uniform bathymetry with fewer bathymetric edges to support large concentrations of euphausiids.

The Cape St. James area is the convergence of several flows that could concentrate food supply. As long as a feeding fish can maintain its position against the currents in this area, it will receive a much higher contact rate with food particles than in many other areas in PNCIMA.

There is much less information on the distribution of pelagic species. Pacific herring and Pacific sand lance are known to be abundant in PNCIMA. The distribution of herring spawning grounds are well known (see Chapter 2, section 2.5.1, Map 2.12, and Appendix H: Pelagic Fishes, Section 2.0), however their distribution during the feeding period of their life cycle is poorly understood. Both species are caught in bottom trawl surveys, but are poorly represented relative to their abundance in nature and relative to groundfish species for which the surveys were designed. Catches of both species are higher in Hecate Strait than in Queen Charlotte Sound. This is likely because the depths in Hecate Strait include more seafloor of the appropriate depth for these species. Within Hecate Strait, these pelagic species appear to be more abundant in the northern area than to the south. Thus, within Hecate Strait at least, the distribution of pelagic species is similar to that of groundfish.

The overlap in euphausiid and fish distributions is unlikely to be coincidental, but rather a clear trophic linkage. Both are influenced by bathymetry, which influences circulation, which is driven by tides and wind, and enhanced by the estuarine circulation.

1.4.2 Species Richness

The recent expansion of synoptic groundfish bottom trawl surveys in PNCIMA provides a new source of information on species richness in the area. The mean numbers of fish species taken per survey tow in the period 2003-2005 are plotted in Figure 1.9. The highest species richness values were seen adjacent to the southern central coast area and through Goose Island trough. These areas have a large range of habitat types including rugged reefs, highly variable bathymetry, exposed bedrock, as well as patches of smoother mud, sand, and gravel. The lowest species richness values occurred over the shallow banks (Goose Island, Middle, Dogfish) as well as in McIntyre Bay north of Graham Island. These areas have a more homogeneous habitat type dominated by outwash sand and gravel.

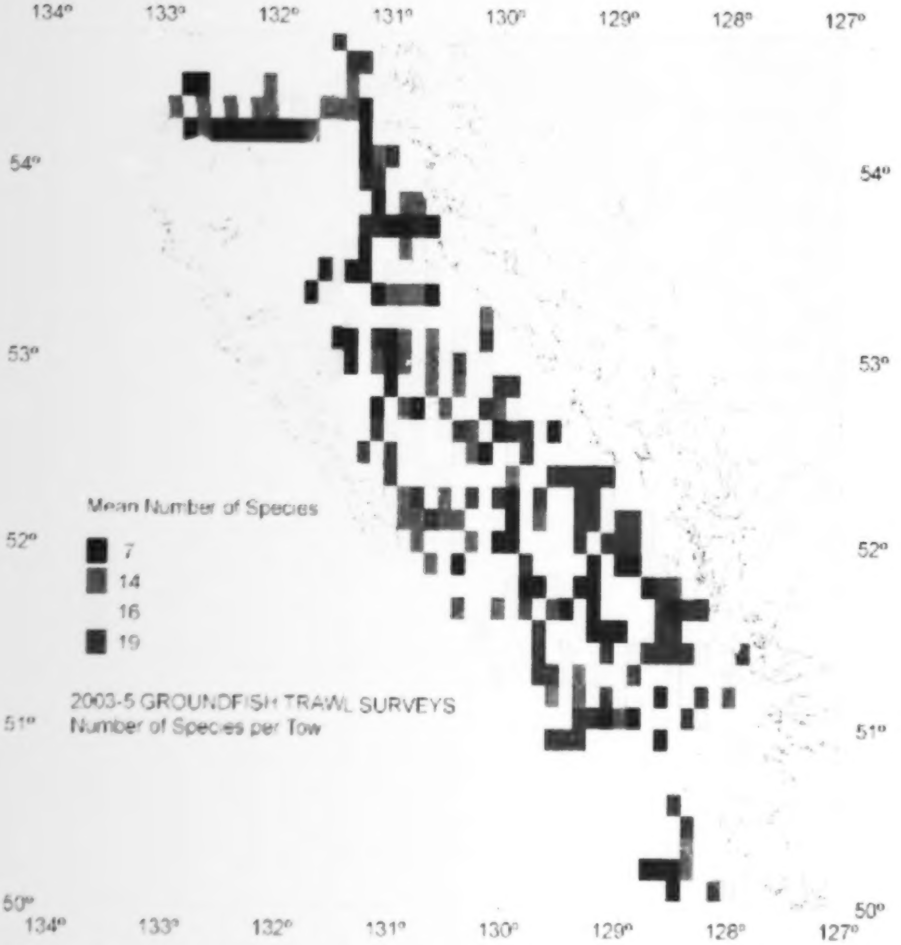

134°
133°
132°
131°
130°
129°
128°
127°
54°
53°
52°
51°
50°
Mean Number of Species
7
14
16
19
2003-5 GROUNDFISH TRAWL SURVEYS
Number of Species per Tow

Figure 1.9 Spatial distribution of fish species richness (mean number of species per tow) sampled by bottom trawl surveys in PNCIMA 2003-2005. The grid cells were coloured according to the quantiles of the overall distribution. Cells with the highest richness are red, the lowest richness are blue.

1.4.3 Species Distributions

Sinclair *et al.* (2005) examined associations between surficial geology and the distribution of 21 groundfish species caught in bottom trawl fisheries in PNCIMA. Three main groups emerged. The first included shallow water species distributed over sand and gravel habitat that is exposed to considerable disturbance and reworking from tidal and storm energy. The species were rock sole, big skate, English sole, spotted ratfish, Pacific halibut, lingcod, Pacific cod, and petrale sole. This habitat type is likely to be less susceptible to anthropogenic disturbance. These species tended to have relatively short life spans and had the fastest growth rates. A second group occupied deeper waters and a soft silt and mud bottom type that was less exposed to disturbance from natural causes. The species were longnose skate, arrowtooth flounder, spiny dogfish, rex sole, sablefish, and Dover sole. Given the finer sediments and less exposure to natural disturbance, this habitat may be more susceptible to anthropogenic disturbance than the former. These species had intermediate life spans and growth rates. The third group was in deep water over firm glaciomarine mud and glacial till habitats. All species in this group were from the genus *Sebastes* (including boccacio, yellowtail, silvergray, rougheye, redbanded, yellowmouth rockfish and Pacific Ocean perch) and were the slowest growing and longest lived group. A fourth group could be added to this list of species/geological associations, the inshore rockfish species which includes copper rockfish, quillback rockfish, and yelloweye rockfish. These species are taken in hook-and-line fisheries in shallow coastal reef areas. These habitats are often covered with thick epifauna and macrophyte communities that provide a buffer from natural forces such as waves and storms. However, the epifauna and macrophytes are highly susceptible to anthropogenic removal. As with the other *Sebastes* species, these have long life spans and slow growth rates. An interesting fifth component is the Dungeness crab which is found in abundance in the shallowest area of northern Hecate Strait and McIntyre Bay where the sand bottom is constantly being reworked by tides and storms. This species has a shortest life history and fastest growth rate of all the species listed here, surviving for only five to six years.

The general pattern here is for species with greater scope for growth, *i.e.,* high growth rates and short life spans, to occupy habitats that are more resilient to disturbance.

1.5 TROPHIC CONNECTIONS

Three general food web systems can be defined for the PNCIMA region: phytoplankton-based systems; nearshore (macrophyte)-based systems; and detritus-based systems. Strictly speaking the latter (detritus-based) systems are also derived from phytoplankton or macrophyte production, but enough marine organisms feed directly or indirectly on detritus to warrant its own food web, at least in the context discussed here. Almost nothing is known about the microbial loop in this region, although studies have been conducted to the south off Vancouver Island and in the Strait of Georgia. Elsewhere and on theoretical grounds it has been suggested that the microbial loop can divert an important fraction of primary productivity away from higher trophic levels. If some of this microbial production does make its way to higher trophic levels, it does so by increasing the number of trophic links, which decreases the efficiency of the transfer of energy, thereby decreasing the overall production of these higher trophic levels (Ware 2000).

Information on plankton and detritus-based food webs in the PNCIMA region is largely based on direct observations of stomach contents (mostly from groundfish and some pelagic species) and on model studies using ECOPATH (Christensen and Walters 2004). There are several significant unknowns in both of these approaches to food-web analyses. Direct observations are effort-intensive, and tend to be conducted for only a short period of time on selected surveys. They rarely provide extensive coverage of species throughout the entire region or in all seasons. Model studies using ECOPATH require values for many parameters for all groups in the model; these are based on observations as much as possible, but adequate data for most species are lacking. Estimates from similar taxonomic groups and from elsewhere are used to provide possible values, and simulation studies are usually conducted to evaluate system sensitivity to key parameters. In addition, marine ecosystems are unusual (compared with terrestrial ecosystems) in that most species go through very large changes in body size, shape, and habitats between egg, larval, and adult stages. Larval and adult stages of the same species could easily be considered as different species, with predators and prey changing roles as they grow. Such complex life history changes are rarely included in food web models or stomach content analyses, but may be important at stabilising or de-stabilising marine ecosystems.

The ECOPATH modelling approach is described by Christensen and Walters (2004). In the model constructed for northern BC (broadly equivalent to the PNCIMA region), 53 functional groups were defined. These groups range, with varying degrees of resolution, from phytoplankton, detritus and macrophytes to copepods and euphausiids, to small and large crabs, to forage fishes, to juvenile and adult stages of pelagic and demersal fishes, to seabirds and whales (Ainsworth *et al.* 2002). These analyses illustrate the clear separation between those groups that feed within a phytoplankton-based food web, and those groups that feed within a primarily detritus-based food web.

Using observations of stomach contents of demersal fishes collected during surveys in 1985 and 1987, Pearsall and Fargo (2007) identified three main types of feeding: benthivores, planktivores, and piscivores. They further identified five main feeding strategies: euphausiid feeders, shrimp feeders, benthic (macro- and meiobenthos) feeders, macrobenthic feeders, and piscivores. They found that benthic feeders showed more stability among locations and seasons in their diets than did piscivores. Ontogenetic variability in diet was also more apparent for the piscivores, with juveniles often feeding to a larger extent on macrobenthic organisms than the adults. Appendices to this report (*e.g.*, marine plants, invertebrates) also present schematic food web diagrams illustrating linkages among various groups of species.

Nearshore systems are defined as those for which organic carbon is largely derived from terrestrial sources and/or macrophytes. These regions are limited by depth, in particular to depths shallow enough for the euphotic zone to support the growth of macrophytes (typically to about 35 m in these coastal regions; Sloan and Bartier 2000). The most important macrophytes in the PNCIMA region are kelps and eelgrasses. Estimates of the productivity of giant kelp (*Macrocystis* sp.) in California found that photosynthesis was greatest near the sea surface, was reduced to 5-10% of this surface value at 4 m depth, and was reduced to 0.5-2% of surface values at 8 m depth (Mann 1982 p.59). Estimates of the daily net production of giant kelp beds in California have found sustained growth rates of 1-4% of biomass per day (Mann 1982 p.59); the production to biomass (P/B) ratio estimated by Ainsworth *et al.* (2002) for macrophytes in northern BC was 5.3 yr^{-1} (the P/B ratio estimated for phytoplankton was 179 yr^{-1}, *i.e.*, over 30 times the growth of macrophytes). However, relative to the area over which phytoplankton are distributed, a rough estimate suggests that phytoplankton contribute substantially (5,000-10,000 times) more primary productivity to the PNCIMA region than do macrophytes.

Macrophyte and terrestrial organic carbon serve as critical food sources for the nearshore food-web. They directly support echinoderm and gastropod mollusc invertebrates such as sea urchins and abalone, which in turn are fed upon by fish and sea otters (where they occur). Macrophytes are also critically important as habitat structure-forming organisms, *i.e.*, kelp and eelgrass beds. These provide surface habitat for crustaceans (such as kelp crabs) and for particular life stages of commercial finfish such as herring eggs. They also create an environment for many species of invertebrates and finfish to live within by providing cover and shelter, in particular for juvenile fishes like herring and salmon. They act to increase the supply of drifting phytoplankton and algae by slowing local currents and generating turbulence.

A schematic example of these plankton, detritus, and macrophyte-based food webs for the PNCIMA region is illustrated in Figure 1.10.

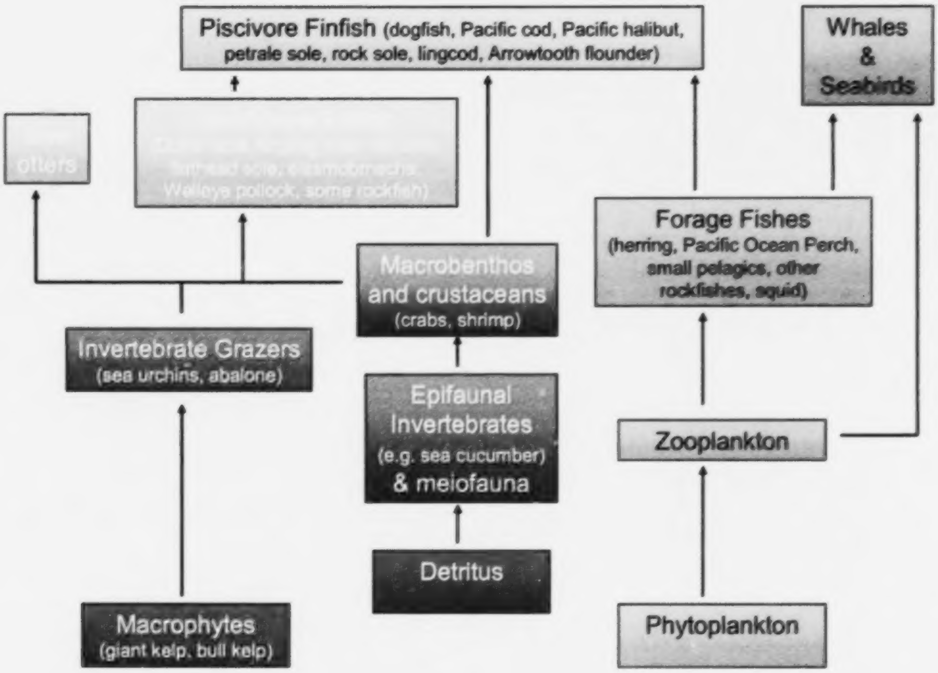

Piscivore Finfish (dogfish, Pacific cod, Pacific halibut, petrale sole, rock sole, lingcod, Arrowtooth flounder)
Whales & Seabirds
otters
flathead sole,
Walleye pollock, some rockfish)
Forage Fishes (herring, Pacific Ocean Perch, small pelagics, other rockfishes, squid)
Macrobenthos and crustaceans (crabs, shrimp)
Invertebrate Grazers (sea urchins, abalone)
Epifaunal Invertebrates (e.g. sea cucumber) & meiofauna
Zooplankton
Detritus
Macrophytes (giant kelp, bull kelp)
Phytoplankton

Figure 1.10 Schematic food webs for the PNCIMA region.

Ainsworth (2006) used the ECOPATH model of the PNCIMA region to explore the system's responses to environmental forcing over the past several decades. He created a "primary production forcing anomaly" pattern at the base of the (ECOPATH) food web that "matched" the temporal dynamics of the system. This pattern was negatively correlated with sea surface temperature (Spearman rank correlation coefficient, $r_s = -0.57$), and indicated reduced primary production from 1975 to 2000 compared with the period from 1950 to 1975. These simulations suggest that primary production and herring recruitment anomalies (another variable for which data could be compared with model outputs) were correlated with environmental time series such as sea surface temperature, the Pacific Decadal Oscillation (PDO) and other regional climate indices, and are therefore linked to the large-scale climate dynamics of the North Pacific. Ainsworth (2006) also concluded that in the northern BC marine ecosystem, lower trophic level dynamics are dominated by bottom-up controls (*i.e.*, climate effects on plankton productivity) whereas higher trophic levels also included top-down (*i.e.*, predator, and fishing) interactions. He concluded that strong predator controls (influences) do not cascade down to the lowest trophic levels of this ecosystem.

The number of linkages in these food web models and diet studies suggests that several important prey items exist within the web, in particular herring, other forage fishes, and large zooplankton such as euphausiids. There is no indication of an overall "wasp-waist" food web structure (*e.g.*, Cury *et al.* 2000), in which energy flows are funnelled through one or a few key species in the middle of the trophic web. The lack of such a feature suggests a more stable trophic structure than might occur in wasp-waist systems such as upwelling areas, and a trophic structure that should be more resilient to natural and human disturbances. However, individual species may have preferences for one or a few key prey items which dominate their diets, either because of spatial or temporal overlaps, behavioural characteristics of predator and prey, and critical biochemical or energy contents. If these prey items are severely reduced in abundance, disappear entirely, or somehow shift their distributions or behaviours so as to become unavailable to these predators, the predator populations may be severely affected. This suggests that, whereas the food web in the PNCIMA region overall may not display a "wasp-waist" structure, such a structure may exist for certain species. For example, the diets of killer whales in this region was composed of salmon (96.7%), the bulk of which (72.2%) were chinook (Ford and Ellis 2005). Such a structure may also exist for large whales such as humpback and blue whales in the PNCIMA region, which feed largely on euphausiids. Identifying which species might be affected in this way, and which prey species might play "wasp-waist" roles, could be done using food web models such as ECOPATH.

1.6 MIGRATORY SPECIES

Section 1.3 discusses the productivity of "resident" species of the PNCIMA region, *i.e.*, those species which spend all of their life within the central and north BC marine ecosystems. Like much of the coastal and continental shelf regions of the northern NE Pacific, however, the PNCIMA region produces a large number of fish which leave the region as juveniles and return as adults, such as Pacific salmon. The region also receives a considerable number of species which migrate to or through it from elsewhere. Such migratory species include marine birds, fish, and marine mammals such as pinnipeds and whales.

The PNCIMA region is on the migratory route for many species of birds which summer in the Arctic. They use the offshore, nearshore, and inter-tidal resources of the PNCIMA region to fuel their migrations to and from their Arctic feeding grounds. Juvenile salmon (and adult salmon during their return migrations) also use the resources of this region during their migrations north along the North American coast. Observations since the late 1990s have found that juvenile pink, chum, and sockeye salmon are quite abundant in the PNCIMA region from June to November (Figure 1.11), likely representing continual migrations of fish from sources to the south (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2006). Marine mammals such as pinnipeds (*e.g.*, Stellar sea lion) and Mysticete whales (*e.g.*, humpback, fin, and blue whales) migrate into the PNCIMA region in certain seasons to feed on abundant zooplankton (especially euphausiids) and forage fish (*e.g.*, herring).

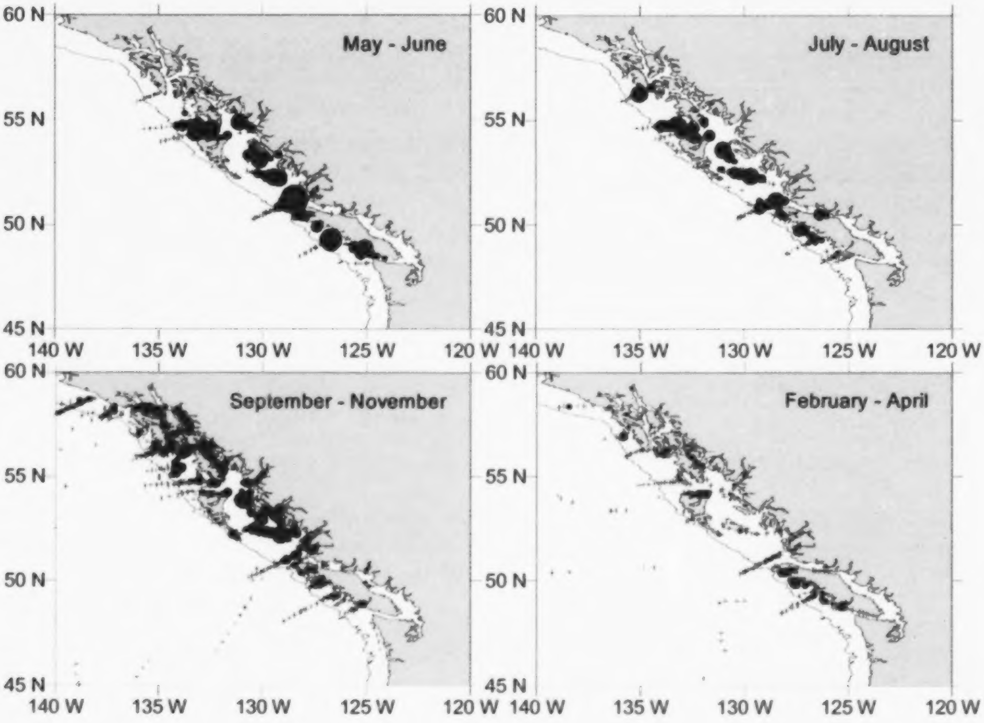


Figure 1.11 Seasonal distribution of juvenile sockeye salmon (*Oncorhynchus nerka*) in the PNCIMA region from surveys conducted since 1998 (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Migrations of marine fish into the PNCIMA region occur in a different fashion to the migrations of marine birds and mammals. With the exception of Pacific hake, whose life history has evolved to include summer migrations from California to BC waters to feed on euphausiids, most other species migrate into the PNCIMA region in association with changes in environmental conditions – in particular when conditions become unusually warm. Such migrations are most obvious during El Niño conditions (*e.g.*, Wing *et al.* 2000) but can also occur during other warm periods (*e.g.*, DFO 2005). Most of these species are pelagic fish or invertebrates such as Pacific sardine, northern anchovy, and ocean sunfish. The timing and duration of their appearance in PNCIMA waters also tends to be less regular than for seasonal migratory species such as birds, mammals and Pacific hake, but they tend to be most evident during summer of warm years.

These species represent three different groups and strategies for the use of the PNCIMA region by "non-resident" species. These strategies are:

- *stop-over* migrants, such as marine birds migrating to the Arctic and salmon originating from rivers to the south which migrate through the PNCIMA region on their way north as juvenile and south as adults;
- *destination* migrants, such as whales, Stellar sea lions, and Pacific hake which migrate into the PNCIMA region from elsewhere to feed, usually during spring and summer; and
- *environmental* migrants, such as warm water zooplankton and pelagic fish and invertebrates which extend their ranges and distributions northwards with warm conditions and retract southwards with cool conditions.

It is evident that the extent and dynamics of use of the PNCIMA region will be different for species in each of these categories, and will depend on the factors driving the migrations.

The net impact of such migratory species on the PNCIMA region is unclear. For example, do these migratory species represent an import and net gain of energy into the PNCIMA region from other regions, and is this net import critical to the functioning and sustainability of the PNCIMA ecosystems? Or, do these migratory species represent a net loss of energy from PNCIMA to other regions, so that the PNCIMA region has an important role in supporting external ecosystems? Such questions represent significant unknowns as to how the PNCIMA marine ecosystems are connected with other adjacent and distant marine ecosystems.

A reasonable starting hypothesis is to suggest that migratory species represent a net loss of energy from PNCIMA and an export to other ecosystems. Most obvious are *stop-over* migrants which use the PNCIMA region to feed and refuel during their long-distance migrations but which do not reside long enough within the PNCIMA system to become significant prey for resident species. Large *destination* migrants may represent a similar loss of energy from PNCIMA as there are few resident predators on these species in the PNCIMA region.

There is, however, a fourth category of migrating species which do play a very significant role in importing energy and nutrients largely derived outside of PNCIMA into the region. These are the Pacific salmon that originate from the lakes and rivers within the terrestrial boundaries of PNCIMA, migrate through the coastal and shelf ecosystems to the open NE Pacific, and return to their natal streams as adults to die (Figure 1.12). As a result of this migration they import significant quantities of "marine-derived" nutrients, (*i.e.,* nutrients that were obtained while feeding and growing in the open ocean) to the terrestrial ecosystems of coastal central and northern BC. With the excessive rainfall in this region these coastal terrestrial ecosystems tend to be nutrient poor; nutrients derived from salmon migrations provide an important ocean-terrestrial link that re-supplies these essential nutrients to terrestrial systems.

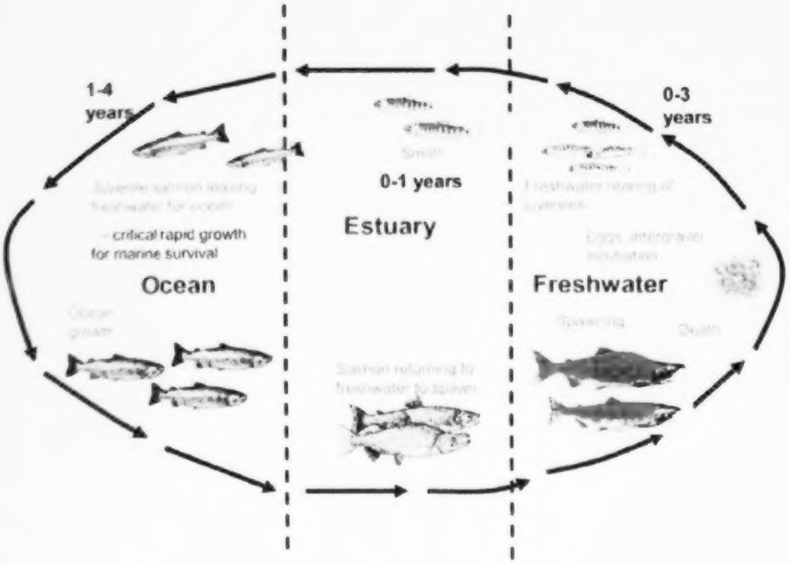

1-4 years
Smolt
0-1 years
0-3 years
Juvenile salmon leaving freshwater for ocean
– critical rapid growth for marine survival
Estuary
Freshwater rearing of juveniles
Eggs, intergravel incubation
Ocean
Freshwater
Ocean growth
Spawning
Death
Salmon returning to freshwater to spawn

Figure 1.12 Typical life-cycle of Pacific salmon showing the ocean-terrestrial connection and the export of marine-derived nutrients to terrestrial ecosystems (from Johannes *et al.* 2003).

1.7 TEMPORAL PATTERNS OF PRODUCTION

Temporal patterns of the production and biomass of lower trophic level organisms such as phyto- and zooplankton for a generic location in the open waters of the Hecate Strait – Queen Charlotte Sound region have been modeled by Ware and McQueen (2006c). They developed a simulation model that tracks the flow of biomass from phytoplankton through to copepods, euphausiids, and other zooplankton. The model is forced by water temperature, hours of sunlight, wind mixing, and upwelling (using upwelling-favourable winds as a proxy); note that they excluded from their model any winds that were not upwelling-favourable, as they believed these generally are not conducive for the production of phytoplankton. Freshwater flows and their effects on the vertical stability of the water column were not included. The model simulates daily phytoplankton production from 1 March to 30 November of each year. The model is fully described in Ware and McQueen (2006b).

Using input data from the past 4 decades, the model estimates that primary production averaged about 223 g C m^{-2} yr^{-1}, which would make this region less productive than the Strait of Georgia but much more productive than the oceanic Gulf of Alaska. Primary production was low during the 1960s in their simulation, increased through the 1970s to the early 1990s, and then declined slightly in the mid-1990s (Figure 1.13). The strongest driver of these decadal-scale patterns was the average upwelling wind speed during the production season ($r^2 = 0.58$; Figure 1.13), which was increasing during the 1970s and 1980s, although the moderate value of the regression coefficient indicates that many other factors, such as sunlight, wind mixing and zooplankton grazing, also play important roles in regulating primary production. The principal production season in this region runs from March to November.

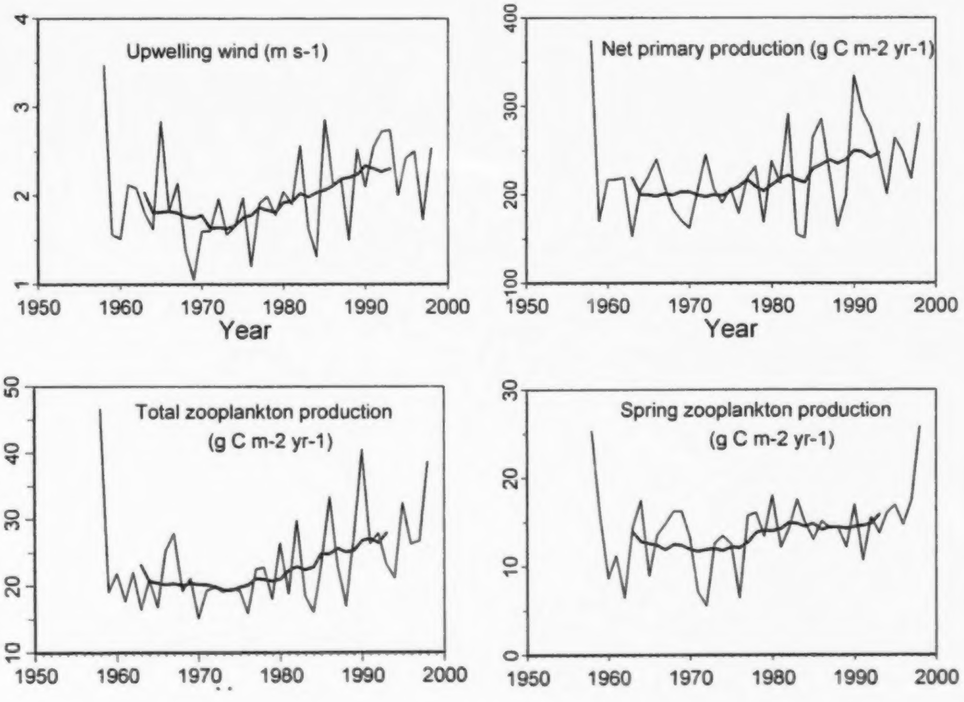


Figure 1.13 Annual (March to November) average upwelling-favourable wind speed, modelled net primary production, total zooplankton production, and spring zooplankton production, 1958-1998, from the Hecate Strait lower trophic level model of Ware and McQueen (2006c). Heavy line is a decadal-scale (11 year) moving average.

Upwelling-favourable winds are expected to bring more nutrients into near-surface waters along the east side of Hecate Strait and the west coast of the Queen Charlotte Islands in summer. However, it is important to remember that the Ware and McQueen (2006c) study identified upwelling winds only by the direction of the wind, not by the ocean processes associated with this wind. The strength of upwelling is not well known, and other processes associated with NW winds might have equal or greater impact on primary production in some regions. For example, Coriolis force directs surface currents to the right of the wind in the Northern Hemisphere. Studies of winds and surface drifters in the three major basins (Dixon Entrance, Hecate Strait and Queen Charlotte Sound) found the surface flow was on average about 35° to the right of the wind (Crawford *et al.* 1996; 1999). Thus NW winds would push waters away from an eastern shore. This water could be replaced by deeper waters (upwelling) or the surface flow could be mainly surface outflow from inlets such as Fitz Hugh Sound and Chatham Sound. Either process would push nutrient-rich waters into the regions we note later as more highly productive.

As expected, total zooplankton production and spring zooplankton production also followed similar decadal patterns, although the decadal trend is not as pronounced (except at the end of the 1990s) in the spring zooplankton time series. Annual total zooplankton production was reasonably well correlated with the net primary production ($r^2 = 0.76$). Zooplankton converted primary production into zooplankton biomass with an efficiency of about 10%. The model suggests a significant ($r^2 = 0.42$) positive relationship of this zooplankton ecological efficiency with the sea surface temperature (SST), such that the ecological efficiency was less than 9% for SST less than 11 °C, and was greater than or equal to 12% for SST greater than 12 °C. Ware and McQueen suggest this implies that zooplankton become more efficient grazers at warmer temperatures, and occurs in the model because grazing rates of zooplankton increase exponentially with temperature. In contrast to total zooplankton production, the spring zooplankton production was most well correlated ($r^2 = 0.63$) with the average SST, and only very weakly correlated ($r^2 = 0.09$) with the annual net primary production, suggesting that late winter-spring conditions and phytoplankton production may have a greater influence on spring zooplankton than annual conditions.

Ware and McQueen (2006a) compared their model output (updated to 2002) with observed data for the period since 1998. They found the correlation between chlorophyll *a* concentrations derived from the model and chlorophyll *a* concentrations that were observed from the SeaWiFS satellite to be $r^2 = 0.37$. Comparisons of the model outputs with observed annual anomalies in the nestling growth rates of Cassin's Auklet chicks on Triangle Island off the northwest tip of Vancouver Island were most highly correlated with the date of the spring phytoplankton bloom ($r^2 = 0.86$) and with the modeled copepod production rates. These results are broadly consistent with observations of the responses of seabird populations to ocean climate changes at the northwestern tip of Vancouver Island (Bertram *et al.* 2005; Hedd *et al.* 2006). Correlations between model estimates of spring zooplankton, copepod and euphausiid production and the growth rates of Pacific herring populations in Hecate Strait and Queen Charlotte Sound were about $r^2 = 0.37$.

The NASA SeaWiFS Ocean Biology Processing Group has made available satellite ocean colour data obtained since 1997, resolved to monthly time scales and 9-km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml)[1]. For the PNCIMA region, the mean monthly and annual mean (January to November) chlorophyll *a* concentrations are shown in Figure 1.14. They indicate relative constancy of the mean annual chlorophyll concentration from 1998-2005, except for 2002 which had very high chlorophyll during spring. The data also indicate that peak spring (April-May) chlorophyll concentrations are significantly (t-test, P=0.018) higher from 2002-2005 (mean = 2.8 mg m^{-3}) compared with 1998-2001 (mean = 1.8 mg m^{-3}).

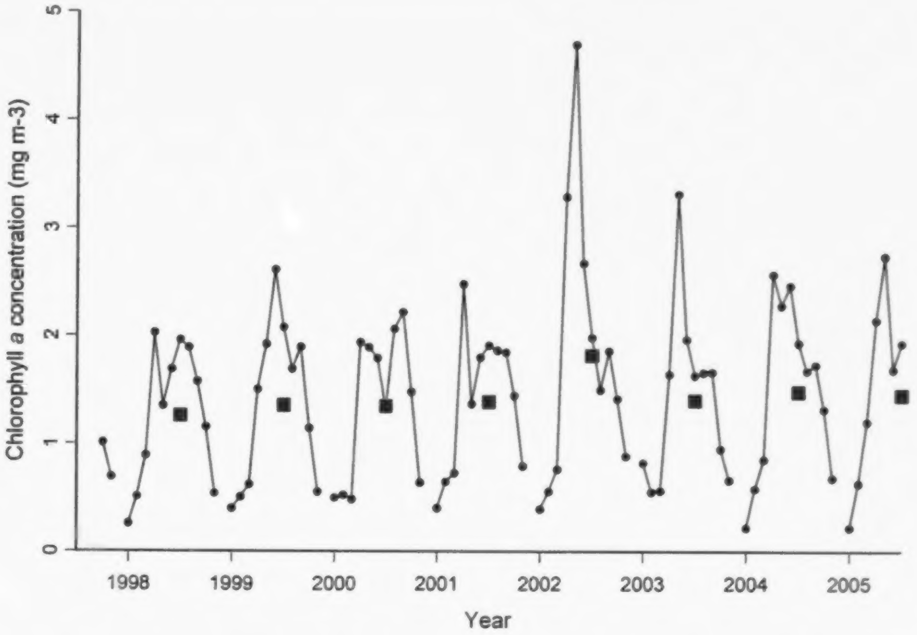


Figure 1.14 Monthly mean chlorophyll *a* biomass (mg m^{-3}) for the PNCIMA region as measured by the SeaWiFS satellite sensor at 9 km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml). Note no data are available for December of any year. Large squares represent the annual average chlorophyll *a* biomass calculated from monthly averages from January to November of each year.

The long-term catches of "resident" finfish (which excludes Pacific hake, sardine, and pink, chum, sockeye, and coho salmon), as used by Ware and Thomson (2005), from 1920-2004 show the very high catches of pelagic species (herring) during the 1960s, followed by their decline, the closure of the herring reduction fishery, and the introduction of most groundfish fisheries since the 1970s (Figure 1.15). These patterns should be comparable with the time series of plankton as produced by the model of Ware and McQueen; however, the catch series is too highly regulated by management actions and such a comparison inferring direct control of annual variations in fish yields by annual plankton production would be meaningless.

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[1] The images and data used in this study were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

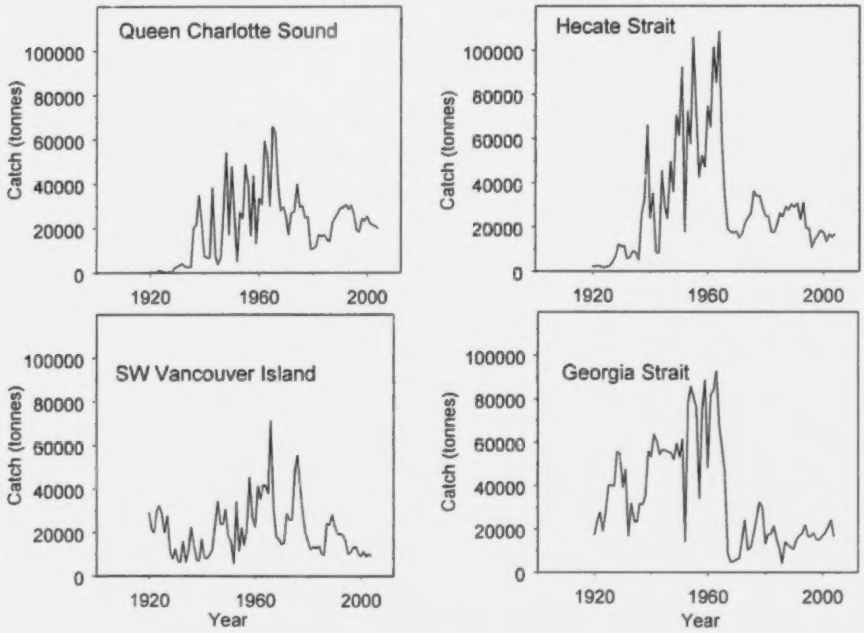

Figure 1.15 Annual catches of "resident" fish (all finfish species excluding Pacific hake, Pacific sardine, pink, chum, sockeye and coho salmon) from 1920-2004 in two southern regions and two PNCIMA regions of the BC coast.

The longest series of fishery independent indices of groundfish species biomass in PNCIMA are available from the Hecate Strait Assemblage Survey which began in 1984 and was carried out approximately every two years until 2003. Twenty-one individual species time series were selected for comparative analysis. Cluster analysis was used to group time series with similar temporal trends. Four clusters emerged (Figure 1.16). One group comprising 7 species (arrowtooth flounder, Pacific sanddab, Dover sole, slender sole, flathead sole, spotter ratfish, and rex sole) showed an increasing trend over the entire time series with an approximate four-fold increase in biomass (Figure 1.17). Two other groups showed an initial period of increase, followed by a decline to the late 1990s, and an increase in the early 2000s. These 2 groups accounted for 12 species. The final group that included Pacific cod and spiny dogfish, showed a downward trend throughout the time series.

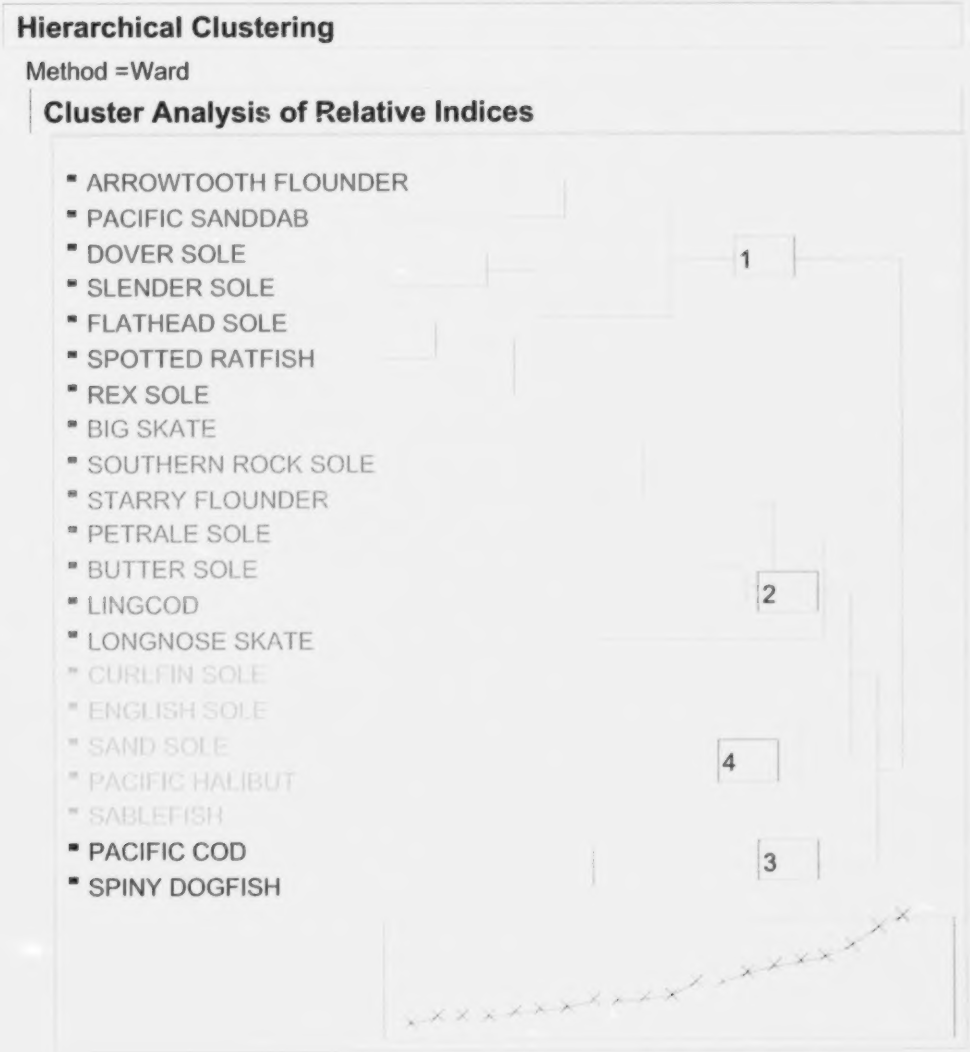
Hierarchical Clustering
Method =Ward
Cluster Analysis of Relative Indices
ARROWTOOTH FLOUNDER
PACIFIC SANDDAB
DOVER SOLE
SLENDER SOLE
FLATHEAD SOLE
SPOTTED RATFISH
REX SOLE
BIG SKATE
SOUTHERN ROCK SOLE
STARRY FLOUNDER
PETRALE SOLE
BUTTER SOLE
LINGCOD
LONGNOSE SKATE
CURLFIN SOLE
ENGLISH SOLE
SAND SOLE
PACIFIC HALIBUT
SABLEFISH
PACIFIC COD
SPINY DOGFISH
1
2
4
3

Figure 1.16 Dendrogram from a cluster analysis of relative biomass indices for 21 groundfish species taken in the Hecate Strait Assemblage Survey, 1984-2003. The line graph in the bottom right indicates the dissimilarity at each cluster join. The species time series were standardized to the individual series means. Agglomerative clustering was used with Ward's method. Four clusters were identified.

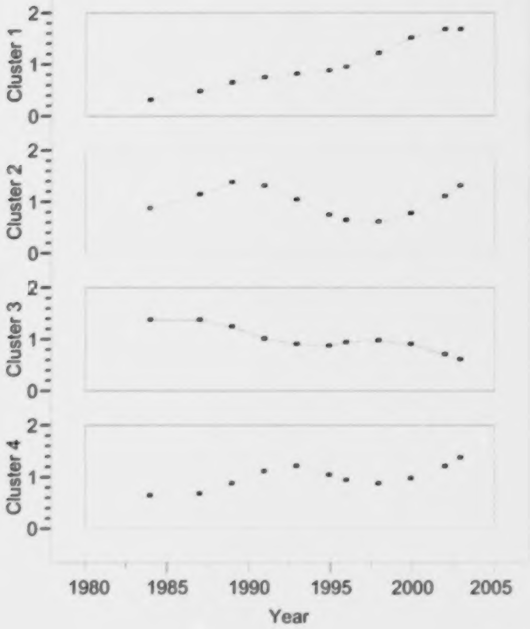

Figure 1.17 Smoothed time series of relative biomass of 4 species clusters identified in a cluster analysis of the Hecate Strait assemblage survey results, 1984-2003.

There is some correspondence between these trends in biomass with trends in primary and secondary production in PNCIMA, modulated to a certain extent by fishing. The Ware and McQueen (2006c) model predicts a generally increasing trend in primary and secondary production in PNCIMA over the time period of this survey. This supports the monotonic increase in biomass of the first cluster. The species in cluster 1, with the exception of Dover sole, are of limited commercial value and are mainly bycatch in the groundfish fisheries in the area. The species in the second and fourth clusters, on the other hand, are more important commercially. The intermediate decline in biomass in these time series corresponds to a period of intense fishing effort by bottom trawlers in Hecate Strait (Figure 1.18). The increases in biomass in the most recent years in these time series correspond to a reduction in fishing effort and a continuing increase in primary and secondary production.

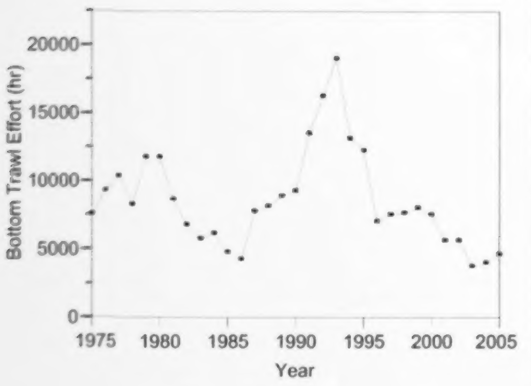

Figure 1.18 Nominal fishing effort (hours) by bottom trawlers in Hecate Strait (PFMC Areas 5CD) at depths less than 150 m, 1975-2005.

The trend in Pacific cod biomass is quite different from the trends described above. Pacific cod recruitment is inversely correlated with pressure-adjusted sea levels at Prince Rupert in their natal winter. This sea level is proxy for flow through the strait and the advection of eggs out of Hecate Strait following spawning. A recruitment mechanism related to advection/retention of eggs and larvae has been proposed (Tyler and Crawford 1991) and confirmed with more recent data (Sinclair and Crawford 2005). These analyses found greater statistical support for the advection/retention mechanism than for growth during juvenile stages. Advection characteristics in the area were not favourable to good cod recruitment in the 1990s. This was exacerbated by intensive fishing for the species. It may be that Pacific cod responds to a different recruitment mechanism than the majority of groundfish species in PNCIMA.

There has been an increasing trend in abundance of many marine mammal populations in PNCIMA. This includes several baleen whale species, many of which visit PNCIMA during their feeding seasons. Sea lion and seal populations are on the increase, as are the reintroduced sea otters. The exception would be the resident killer whale populations which are still at very low abundance in PNCIMA. Those species that have been increasing had all previously been the subject of intense removals by humans, either for commercial reasons or were culled. However, these removals ceased several decades ago. It is difficult to tell whether their recent increases in abundance are a response to increased production in the area or a response to reduced harvest. But, these animals feed at several different trophic levels and their increases in abundance may have some effect on the trophic balance in PNCIMA.

1.8 SUMMARY

The geological environment forms the underlying habitat of the area and significantly affects the physical functioning of PNCIMA.

- The steep and rugged coastal mountains affect climate, rainfall and watershed function.
- The valleys and fjords that cut into these mountains and extend to the adjacent seafloor result in the dominance of estuarine circulation in the nearshore environment and create a sediment-starved shelf.
- The abundant mainland islands create many kilometres of protected and semi-protected coastline and waterways.
- The Queen Charlotte Islands act as a retentive barrier to outflow of water from PNCIMA.
- The glacially scoured continental shelf with its cross cutting troughs form several bathymetric edges and affect currents and circulation in the area.
- The dominant, glacially derived sediments are likely to be a controlling factor in benthic habitats.
- The Queen Charlotte Basin beneath the continental shelf has the potential to contain significant oil and gas reserves.

The proximity of the Pacific Ocean moderates BC's coastal climate, producing relatively warm winters and cool summers compared to the interior of British Columbia.

- Two large scale pressure systems over the northeast Pacific control much of the PNCIMA weather and climate. The Aleutian Low tends to dominate in winter. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC and Alaskan coasts. The North Pacific High dominates in summer and tends to deflect storms northward during this time. These pressure systems and their associated winds also drive the main ocean circulation patterns of the northeast Pacific.
- PNCIMA is located in a transition zone between a northerly area dominated by the Alaskan current system and a southern area dominated by the California current system.

The combined influences of a semi-enclosed basin, varied bottom topography, and fresh water input set PNCIMA apart from other areas of the North American west coast.

- Most of PNCIMA is relatively enclosed geographically, with the Queen Charlotte Islands enclosing most of its northern portion, resulting in little advection of water to the deep ocean in summer. As a result, plankton are more likely to be retained in these basins, not lost to the ecosystem. This contrasts with upwelling regions to the south off California, or regions of SE Alaska where shelf waters are swept offshore in summer.
- Most of the advection out of PNCIMA that does occur is in winter from Dixon Entrance, and at Cape St. James into Haida Eddies. It may be that nutrient-rich oceanic waters replace the advected water in time for the spring blooms.
- High phytoplankton abundance is often associated with areas of high freshwater input. However, the lack of strong tidal mixing of river outflow into deep water near fishing banks sets PNCIMA apart. In PNCIMA, we find less river flow discharging into poorly mixed waters, and although some regions such as Chatham Sound and Fitz Hugh-Smith Sound outflows support plankton production, they do not have sustained, strong productivity. Interestingly, the northeast sector of Hecate Strait supports high fish biomass. This is adjacent to channels where Skeena River water goes through deep well-mixed channels on its way to Hecate Strait, so this mixing might be a factor.
- The steep edges of Dixon Entrance and the three troughs that transect Queen Charlotte Sound and Hecate Strait focus convergent processes that are likely to enhance zooplankton and subsequent fish production.
- There is strong seasonal variability that exceeds interannual variability.
- The area is less affected (in general) by large-scale industrial activities; fishing is the major human forcing to which this system is exposed.
- Retention: In northern to central Hecate Strait, the outflow in spring and summer is likely low. Regions such as Chatham Sound and eastern Dixon Entrance also experience relatively little outflow of plankton, due to estuarine recirculation in Chatham Sound and the Rose Spit Eddy in eastern Dixon Entrance.

As a working model, northern BC waters can be examined using the "triad" approach of Bakun (1996), which suggests that productive marine ecosystems require an optimal combination of three processes: enrichment (of nutrients), concentration (of nutrients and plankton to levels which promote feeding), and retention (of nutrients and food long enough for predators to utilise the resource). In the PNCIMA region:

- *enrichment* is achieved by upwelling (or a weakening of downwelling winds), by the estuarine flow characteristics of freshwater runoff from the coastal inlets, and tidal and wind mixing – all of which act to bring nutrients closer to the surface where they can be accessed by phytoplankton (and macrophytes in the nearshore region);

- *retention* is achieved by the general topography and relatively weak upwelling of the region, in particular the Queen Charlotte Islands, which block extensive advection of water and its constituents into the deep ocean; and
- *concentration*, which is achieved by bathymetric and hydrographic features and their interactions with the circulation.

This model implies that any process, natural or human, that interrupts any of the three aspects of this triad will impede and possibly reduce the productive capacity and resilience of this ecosystem. For example, the productivity of the system as a whole is influenced by the extent of upwelling favourable winds; should these winds change as a result of natural climate changes (as has happened in the past) then they will have an impact on the productivity of the entire ecosystem. The spatial pattern of plankton productivity will be affected by changes in the hydrological regime; if freshwater runoff changes in timing or amount it can be expected to impact the degree of nutrient entrainment into the upper layers by estuarine processes and the locations at which these processes occur. An example is continuing decrease in glacier size with climate warming. High melt rates at present provide more flow in spring and summer than we can expect in the future once these glaciers have disappeared.

From the analyses currently available, the overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components of the food web, as long as other species occur within the same functional group. Overall, the food web does not appear to display a "wasp-waist" structure, in which energy flows predominately through one or a few species at intermediate trophic positions. However, trophic pathways to individual species may be more constrained (*e.g.*, krill to whales); it is unknown which species may be critically sensitive to the reduction or elimination of which other species.

The ecosystem does receive a large biomass of migratory species: of stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that invade PNCIMA when conditions are unusually warm. These species provide an input of energy and food, but also result in an export of energy from the system. Calculations of the net effect have not been conducted that we are aware of. However, it is likely that there will be a net loss of energy from the system since many of the migratory species (*e.g.*, salmon, birds) pass through the region relatively rapidly and do not stay long enough to be significant prey for resident species. Pacific salmon play a significant role in transferring nutrients from marine to terrestrial coastal ecosystems in the PNCIMA region.

There appears to be a spatially dependent trophic linkage from phytoplankton to fish in PNCIMA. This is consistent with what Ware and Thomson (2005) describe for the North American Pacific coast as well as for the entire BC coast. In PNCIMA, phytoplankton biomass is highest at the southeast end of Dixon Entrance where the freshwater input of the Skeena River is highest, and in the entrance to Queen Charlotte Sound in the south where the high-nutrient inflow from Queen Charlotte Strait mixes with fresher runoff from Fitz Hugh and Smith sounds. These same areas also support the high biomasses of groundfish and pelagic fish.

There is evidence from the model of Ware and McQueen (2006c) that the trend in phytoplankton production in PNCIMA has been upward since the late 1970s. The results from the Hecate Strait Assemblage bottom trawl survey suggest a simultaneous increase in biomass of several groundfish stocks. This upward trend is most clear for a group of lightly exploited species. The trends for other more heavily exploited species was interrupted by a pulse of high fishing in Hecate Strait in the early 1990s. This correspondence supports a largely bottom-up control on groundfish production when fishing is not a factor. An exception may be Pacific cod, which appears to be more strongly influenced by advection of eggs and larvae.

1.9 UNCERTAINTIES AND KNOWLEDGE GAPS

We have tried, in the preceding pages, to pull together a very rudimentary portrait of how PNCIMA works. Some of the linkages we have described are embarrassingly simplistic, and many are very likely to be completely wrong. Hopefully this will prompt others to show where we are wrong and why.

Clearly there are many, many things we do not understand about how PNCIMA works. It would be futile to try and summarize the depth of our lack of understanding. What follows are some points we gleaned from the other sections of this report, what was brought to our attention during discussions with others, and what we thought were important issues to focus on in the near future. This list, by no means whatsoever, should supersede any other list of uncertainties and knowledge gaps that has been developed through other processes.

Terrestrial bedrock geology is quite well understood at the PNCIMA area scale in BC and the level of detail is constantly improving. Submarine bedrock geology is less well constrained. Current knowledge of seafloor sediments and substrate material is patchy and limited by the need to extrapolate between widely spaced sampling points. The advent of multibeam sonar technology is providing extremely accurate information but will take many years to complete a shelf-wide map. The variability in the transport, deposition and erosion of submarine sediments is also poorly constrained but our understanding is likely to improve with technological advances.

While the exact timing of large earthquakes can not be predicted, current techniques allow a high degree of certainty that the subduction zone off of the west coast of Vancouver Island is currently locked and will likely produce an earthquake around magnitude 8 within the next few hundred years or so. The transform fault off the Queen Charlotte Islands is known to produce the occasional magnitude 8 earthquake, but the frequency of this is not well known.

Climate prediction on all time scales is difficult. The complexity of ocean-atmosphere systems and their interaction also prevents sufficient understanding for accurate predictions, although new observational programs are improving climate models through the collection of near real time oceanographic data. Thus, although it is known that climatic conditions are critical to ecosystem function, and that they vary significantly on various time scales, predictive capabilities need to be improved.

Modelling of climate and coupled climate-ocean conditions is limited by computing capacity (most of these efforts require supercomputers), by the complexity of the climate itself, and by a lack of monitoring data, especially over and within the Pacific Ocean. Advances in this area will improve climate prediction capabilities.

A recent analysis was made of BC's climate observation capacity. The 'Review of the Adequacy of Climate Related Observation Networks' (M. Miles and Associates 2003), found that, according to World Meteorological Organization standards, BC is severely lacking in climate and stream gauging, sediment discharge stations, and climate station density and is somewhat lacking in monitoring of evaporation, hydrometric networks and snow course density monitoring. Deficiencies are most common in areas that are remote, high elevation, or have small watersheds. This would describe most of the PNCIMA area. These deficiencies are specifically discussed in terms of the ability to verify and support climate modelling efforts.

Virtually all that is reported here on phytoplankton distribution and bloom timing was taken from satellite imagery that has several drawbacks. These images cover only the surface ocean. As such, they cannot detect deep chlorophyll layers and may underestimate production in well mixed areas where phytoplankton are drawn away from the surface. The images also measure standing stock and may underestimate production in areas where grazing is high. There is a definite lack of field observations of primary production in PNCIMA that should be addressed.

Zooplankton are poorly sampled in PNCIMA. While we have inferred a spatial and temporal linkage between phytoplankton and fish, it must pass through zooplankton. We have little information on when and where zooplankton and ichthyoplankton feed. This is needed to confirm our inferred linkage and to better understand the pathways through which energy flows through these different trophic levels.

Most of the information presented here on fish distribution pertains to adults and is dominated by commercially important species. Comparatively little is known about the distribution of juveniles of these same species, and less yet on larval distributions and spawning locations of these species. However, the available information indicates important ontogenetic differences in life history and distribution.

Information on food web linkages and who eats whom is severely lacking, having been collected only for groundfish species in limited seasons during two years in the 1980s.

We have said little in this report on the ecology of the west coast of the Queen Charlotte Islands. This is because very little is known about this region. The shelf is very narrow with the slope descending rapidly to well over 1000 m along much of this edge. This coast is isolated, poorly charted, and with few refuges from the often severe weather. For that reason, it is probably the least disturbed coastline in PNCIMA. It is tempting to conclude that production in this area is relatively low, however little information is available.

1.10 ACKNOWLEDGEMENTS

We wish to thank the authors of the other sections of this PNCIMA ecosystem overview and others who participated in our workshop held at the Institute of Ocean Sciences on March 9-10, 2006 for sharing their ideas and impressions of the PNCIMA ecosystem. We also thank Barbara Lucas for her editorial comments.

CHAPTER 2: HABITAT USE AND FUNCTIONAL AREAS IN THE PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA

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2.0 INTRODUCTION

This chapter provides a geographical presentation of habitat use for many of the large and/or commercial species in the Pacific North Coast Integrated Management Area (PNCIMA; Figure 2.0). It also summarizes the highlights of habitat use detailed in the appendices to this report - Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA).

In general, little is known about the functional habitat use for most life history stages for marine species in British Columbia (BC). Where it is known, maps show migration routes, spawning areas, rearing areas, foraging areas, and other important habitat areas.

Some of the maps used in this chapter were initially developed in the early stages of the process to identify Ecological and Biologically Sensitive Area (EBSAs) for PNCIMA. Clarke and Jamieson (2006) used a modified Delphic approach with species specialists to identify important areas based on criteria for uniqueness, aggregation, fitness consequences, naturalness, and resilience (Fisheries and Oceans Canada 2005). Functional habitat uses identified during the EBSA process have been indicated in the maps in this chapter, along with any additional habitat information available.

For some species, such as benthic invertebrates, their adult habitat is indicative of most benthic life stages because they move little as adults. The majority of our knowledge of marine species comes from fishery assessments of commercially-harvested species, resulting in bias towards them in fished areas and against non-commercial species and unfished areas.

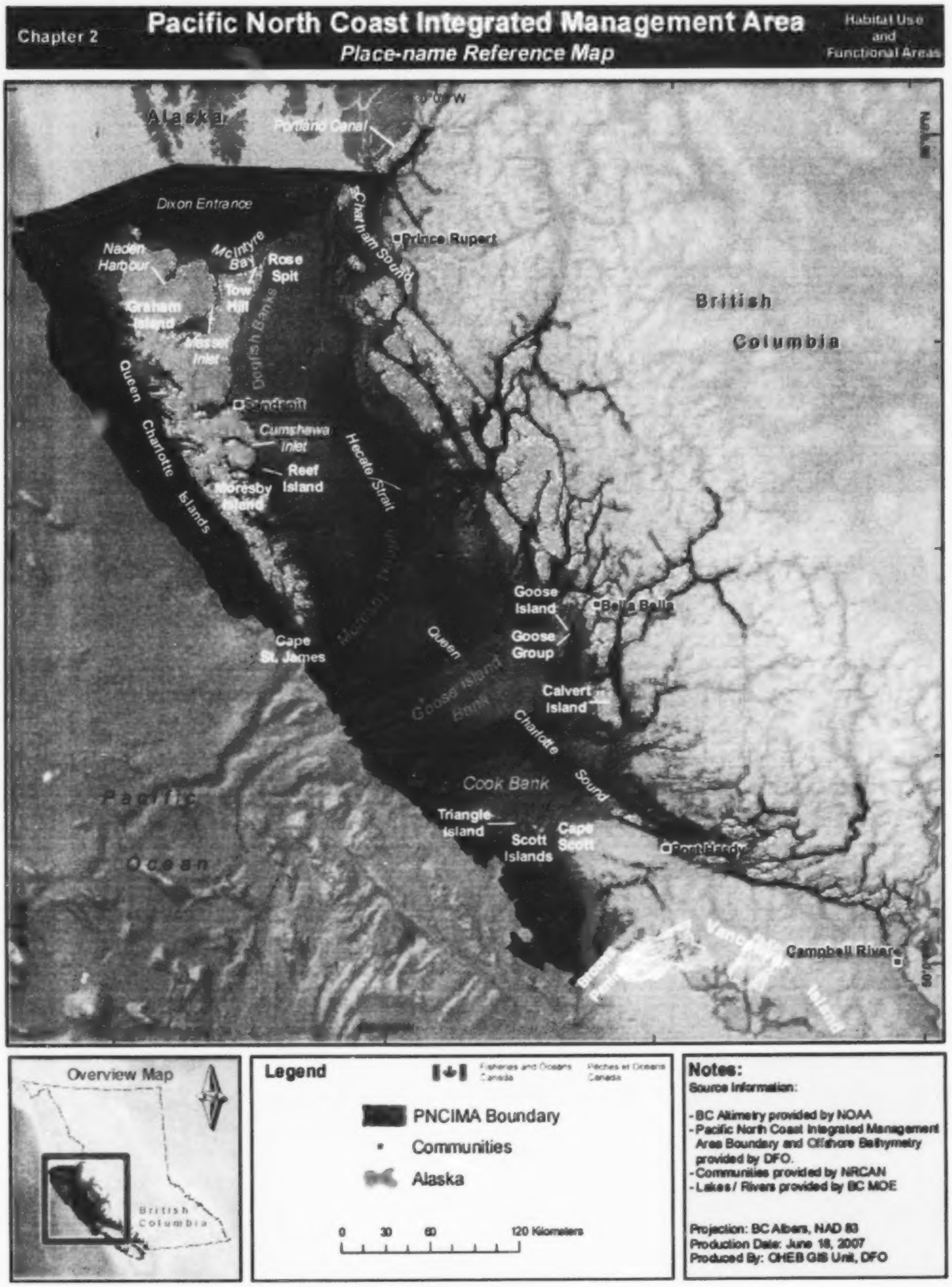

Chapter 2
Pacific North Coast Integrated Management Area
Place-name Reference Map
Habitat Use and Functional Areas
Alaska
Portland Canal
Dixon Entrance
Chatham Sound
Prince Rupert
Naden Harbour
McIntyre Bay
Rose Spit
Tow Hill
Graham Island
Masset Inlet
Dogfish Banks
British Columbia
Queen Charlotte Islands
Sandspit
Cumshewa Inlet
Reef Island
Moresby Island
Hecate Strait
Goose Island
Bella Bella
Goose Group
Cape St. James
Queen Charlotte Sound
Goose Island Bank
Calvert Island
Cook Bank
Triangle Island
Scott Islands
Cape Scott
Port Hardy
Pacific Ocean
Campbell River
Vancouver Island
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Alaska
0
30
60
120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure 2.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 2.

2.1 PLANKTON

Plankton are commonly grouped into three categories: phytoplankton, zooplankton, and bacterioplankton. Phytoplankton supply their own food, through photosynthesis, and thereby provide most of the food energy that supports the rest of the marine food web (see Appendix D: Plankton). Bacterioplankton break down particulate detritus, releasing dissolved nutrients. Both these groups are grazed by zooplankton, which include single celled organisms and the larval and juvenile stages of many benthic and pelagic species. Larval and juvenile zooplankton are discussed in detail in the appendices to this Ecosystem Overview for PNCIMA.

Plankton concentrations vary spatially and temporally, as does the species composition. PNCIMA appears to have moderately high phytoplankton biomass over most of the continental shelf from spring through fall, with very high levels at the entrance to some inlets and fjords. Euphausiid zooplankton, a key prey for some fish and birds, are associated with the three steep-sided troughs in Queen Charlotte Sound. A combination of nutrient enrichment, localized concentrations (*e.g.*, along bathymetric edges), and retention of critical life stages can provide biologically productive pelagic habitats (Bakun 1996).

Plankton are affected by the climatic conditions detailed in Appendix B: Meteorology and Climate and are subjected to the currents detailed in Appendix C: Physical and Chemical Oceanography.

2.2 MARINE PLANTS

Benthic marine plants include two important habitat-forming macrophyte groups, kelp and eelgrass. Temperate kelp beds are one of the most productive ecosystems in the world (Mann 1982). Kelp beds are important spawning and nursery areas for fish and invertebrates, and contribute a significant amount of fixed carbon to the nearshore ecosystem (Duggins *et al.* 1989). Selected kelp beds in PNCIMA were surveyed by the BC Ministry of Agriculture, Fisheries and Food between 1976 and 1996 (BC MAFF 1996). Surveys were conducted using fixed wing aircraft and field trips to the kelp beds to verify species and densities. Biomass estimates for those beds were reported by Lindstrom (1998) and are included in Appendix E: Marine Plants. Kelp beds were extensive in surveyed areas (Map 2.0), but required digital enhancement to increase their visibility on a Large Ocean Management Area (LOMA) scale. Detailed digital maps are available for each area from the Habitat Branch of Fisheries and Oceans Canada.

Eelgrass, *Zostera marina* and *Z. japonica*, form extensive meadows in soft sediments in the lower intertidal and shallow subtidal, mostly in protected waters, such as heads of inlets. These beds provide important habitat and sometimes food for waterfowl, crab, herring and juvenile salmon (BC MSRM 2002). They also stabilize sediments and contribute to nutrient cycling in both direct and indirect ways (Phillips and Menez 1988;

Dunster 2003). An eelgrass bed mapping atlas is available online (Community Mapping Network 2006), but the beds are too small to show on a LOMA scale. Additional eelgrass maps that may be of interest are detailed in Appendix E: Marine Plants.

The Coast Information Team (CIT 2003) identified saltmarsh vegetation, eelgrass beds and kelp beds as the major nearshore habitats because of their high biological productivity and sensitivity to human impacts and because "these categories are recognized ecologically, are protected by policy, and are the best surrogates at this scale to represent a range of habitats" (CIT 2003).

Estuaries are also highly productive habitats where terrestrial, freshwater, and marine ecosystems meet. Although they account for less than 3% of the BC shoreline, they are used by 80% of all coastal wildlife (NRTEE 2005). In BC, 442 large estuaries have been identified from existing mapping products (Pacific Estuary Conservation Program 2004). Of these, MacKenzie *et al.* (2000) has surveyed twenty eight central and north coast estuaries. Their objectives were to acquire site specific information about estuarine ecosystems based on plant community types, to describe the range of estuary types, including biological and geomorphogical information, to create a site classification, and to identify estuaries with particularly high habitat value or rare ecosystems.

2.3 INVERTEBRATES

Invertebrates inhabit the full range of marine environments, intertidal to great depths, benthic to pelagic, mud to rock, and even upon other species. A detailed description of invertebrates species is available in Appendix F: Invertebrates.

Many marine invertebrates are sedentary or move little in their environment, except during larval stages. Some, such as corals and reef forming sponges, form habitat for other species. Coral and sponges may provide essential habitat for some benthic organisms, including many juvenile and some adult fish species (especially rockfish). Important concentrations of coral and sponge have been identified (Ardron 2005), along with occurrences of coral in PNCIMA (Map 2.1) (Etnoyer and Morgan 2003; Jamieson *et al.* in press). Siliceous hexactinellid sponges form reefs in deep waters in Queen Charlotte Sound (Conway 1999).

Commercial molluscs include clams, scallops, abalone, squid and octopus. Clams are found intertidally and subtidally throughout PNCIMA (Table 2.0) on a scale too small for mapping. Their habitat use is summarized in Table 2.1. Geoduck occur throughout the coast in unconsolidated substrates (C. Hand, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Commercial crustaceans include euphausiids, shrimp and prawns, and crabs. Shrimp spawn in late autumn to early winter. Females carry their eggs on their abdomen until the eggs hatch in early spring. The timing of hatching varies by species and by area. It is important to protect breeding females long enough for them to release the eggs (Fisheries and Oceans Canada 2006; Dunham and Boutillier 2001). Larvae are pelagic for approximately three months before they settle. The limited migration activity of adult prawns results in the existence of hundreds of separate stocks. However, meta-populations that share larvae may exist for prawns and shrimp because their lengthy pelagic larval stage may allow dispersal and exchange between populations (Booth 2000; Stocker *et al. eds*. 2001). Nearshore juveniles that occur predominately in channels and near estuaries may be particularly sensitive to habitat alterations (Johannessen *et al.* 2005).

Crab larvae are pelagic, while the adults are benthic. Crabs are soft-shelled when moulting, and then are particularly susceptible to predation and injury. Juveniles tend to moult more frequently per year, whereas adult crabs tend to moult annually; mating occurs when the females moult. Fertilized eggs remain attached to the female's abdomen for 4-5 months until they hatch, usually in late winter to early spring. During the egg incubation period, females often bury in the substrate to protect their eggs. Larvae are planktonic for approximately 4 months before reaching an active swimmer stage. Chances of survival are highest at settlement if the megalopa metamorphoses into a juvenile crab in water less than about 50 m depth. Juvenile crabs of less than 70 mm survive best in lower intertidal and shallow subtidal waters, where they sometimes overwinter. Because juveniles are concentrated in nearshore areas, including coastal estuaries, they are especially susceptible to human activities (Booth 2000).

High concentrations of Dungeness crabs are found in some areas of PNCIMA (Map 2.2). Larvae are found throughout the coast at particular times of year, in the spring around Vancouver Island and in the summer around the Queen Charlotte Islands (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). An ocean gyre off the north coast of the Queen Charlotte Islands retains larvae in productive areas off McIntyre Bay, Rose Spit and Tow Hill (G. Jamieson, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Naden Harbour, Masset Inlet, Portland Canal, and the Prince Rupert region are areas of high adult concentrations.

Two species of Tanner crab occur in PNCIMA, *Chionoecetes tanneri* and *C. bairdi*. *C. tanneri* are found in deep waters of the continental shelf break (Map 2.3). Surviving larvae are likely found only at depth (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). High concentrations of *C. tanneri* are found in the two circled areas in PNCIMA, and further south, off the west coast of Vancouver Island. *C. bairdi* are found in most mainland inlets at depths of 50-70 m, but they do occur as deep as 400 m (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Table 2.0 Summary of clam habitat in British Columbia.

Common and Scientific Name	Distribution	Preferred Habitat	Growth Rate	Spawning Time	Food Sources	Notes
Butter Clam *Saxidomus gigantea*	Common in protected beaches in bays and estuaries throughout BC.	Lower 2/3 of intertidal zone to max. 15 m subtidal depth. Typically in beaches of porous sand, broken shell, gravel and mud. Burrow to max of 25 cm. Permanent burrows.	Slow growing. Legal size 38 mm, (5-6 yrs. Strait of Georgia;7-8 yrs. Alert Bay, 9^{+}yrs north coast) Max. age, 20^{+}yrs. Max. size, 130 mm.	Sexually mature at 38 mm (~3 yrs). May in Strait of Georgia, later in north coastal areas.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	
Manila Clam *Venerupis philippinarum*	Currently range from Laredo Inlet in the central coast to California on protected beaches.	From 1 m intertidal zone to well above mid-intertidal level. Does NOT inhabit subtidal. Mixed substrates of gravel, sand or mud. Permanent burrows.	Harvestable at 38 mm, 3-4.5 yrs of age in the central coast. Sexually mature 2-3 yrs Max. size 75 mm, approx. 10 yrs. Max. age 16 yrs. in BC.	August in central coast. Mid June and Sept. in Strait of Georgia.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	Require surface temperatures of 14°C or greater to permit gametogensis, spawning and larval development. Intentional introduced in north and central coasts but failed to produce sustainable populations. Natural recruitment in central coast probably from Quatsino Sound. Limited competition with native clams.
Native Littleneck Clam *Protothaca staminea*	Common in protected beaches in bays and estuaries along the coast, and near rocky outcrops on outer coastal areas.	Slightly above mid-intertidal to a max. subtidal depth of 12 m. Firm gravel beaches. Associated with Butter clams. Burrow 3-8 cm below surface, max. depth 15 cm. Permanent burrows.	Rapid growth to 5 yrs. of age, then decreases. Legal size, 38 mm (5-6 yrs. in the north coast, 3.5 yrs. south coast). Max. age, 14 yrs. Max. size, 70 mm (~10 yrs.).	Sexually mature at 2 yrs. (25 mm). Spawn April to October.	Suspension feeder, mainly phytoplankton, as well as zooplankton and detritus.	Growth varies from beach to beach and between tide levels on any given beach.

Table 2.0 Continued…

Common and Scientific Name	Distribution	Preferred Habitat	Growth Rate	Spawning Time	Food Sources	Notes
Razor Clam *Siliqua patula*	Surf-swept beaches from Aleutian Islands, AK to California. In BC, two major stocks Long Beach on WCVI and on beaches east of Masset on the northeast coast of Graham Island, QCI.	Mid-tide level to 20 m subtidal depth. Sandy, exposed beaches. Burrow just below surface max. 25 cm; can burrow to depth >60 cm in less than a minute. Do NOT form permanent burrows.	Variable, fastest at lower beach levels. Legal size 90 mm reached in 1-2 yrs. on WCVI 3-4 yrs. on QCI. Max age, 10 yr. Max size, 18 cm.	Sexually mature after 1 yr. (south) and 3 yr. (north). July and early Aug. on Queen Charlotte Islands. May and June on Long Beach, WCVI.	Filter feeder, mainly planktonic diatoms, but also zooplankton and detritus.	Currently found only on QCI in PNCIMA region.
Varnish Clam *Nuttallia obscurata*	Well established in Strait of Georgia and Barkley Sound. Most northern occurrence published to date is Cameleon Harbour in Johnstone Strait, but species is actively spreading.	High intertidal. Sand/gravel beaches, particularly loose sand.	Unknown but speculated to be similar to Manila clams. Max size, 69 mm. Max weight, 61 g.	Timing unknown.	Filter feeder, mainly plankton, but also organic detritus.	Associated with Manila and littleneck, softshell (*Mya arenaria*), and *Macoma* clams. Compete with Manila clams over high intertidal zones. Varish clams dominate high intertidal and Manilas mid intertidal.
Cockle *Clinocardium nuttallii*	Common throughout BC but not abundant in any one location.	Shallow burrow, often large adults are exposed. Prefers muddy substrates which are not common in BC (restricted estuaries, bays and channels.	Moderately fast Shell size of 60 mm ~ 3 yrs. of age. Max size , 120 mm.	Cockles are hermaphroditic, unlike the other species mentioned here.		
Soft-shelled clam *Mya arenaria*	Found throughout BC primarily in estuaries.	Soft substrate mud-sand. Mid to upper intertidal area.	Max size, 150 mm.			Commercially harvested of the east coast of North America.

(Fisheries and Oceans Canada 2000a; DFO 2001b, 1999c, 1999d, 2001c, 2001e; Stocker *et al. eds.* 2001; Jamieson and Francis 1986)

Table 2.1 Habitat use for selected invertebrate molluscs in PNCIMA.

IT = Intertidal, ST = Subtidal, BE = Benthic, PE = Pelagic, PL = Planktonic, SP = Sponge Reef, SG = Seagrass Beds, KE = Kelp Beds, ES = Estuaries, MU = Mud, SA = Sand, GR = Gravel, SH = Shell, RO = Rocky

			Life History Function				
Group	**Common Name**	**Scientific Name**	**Migration**	**Spawning**	**Rearing Larvae**	**Rearing Juvenile**	**Foraging**
Bivalves	Geoduck	*Panopea abrupta*		IT, ST, BE, MU, SA, GR	PL	PL	IT, ST, BE, MU, SA, GR
	Horse Clams	*Tresus capax*		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
		Tresus nuttallii		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
	Butter Clam	*Saxidomus gigantea*		IT, ST, ES, MU, SA, GR, SH	PL		IT, ST, ES, MU, SA, GR, SH
	Manila Clam	*Venerupis philippinarum*		IT, MU, SA, GR	PL		IT, MU, SA, GR
	Littleneck Clam	*Protothaca staminea*		IT, ST, ES, GR	PL		IT, ST, ES, GR
	Razor Clam	*Siliqua patula*		IT, ST, SA	PL		IT, ST, SA
	Varnish Clam	*Nuttallia obscurata*		IT, SA, GR	PL		IT, SA, GR
	Cockle	*Clinocardium nuttallii*		MU	PL		MU
	Soft-shelled Clam	*Mya arenaria*		IT, ES, MU, SA	PL		IT, ES, MU, SA
	Pink Scallop	*Chlamys rubida*		IT, ST, MU, SA, GR, RO	PL		IT, ST, MU, SA, GR, RO
	Spiny Scallop	*Chlamys hastata*		IT, ST, GR, RO		PL	IT, ST, GR, RO
Gastropods	Northern Abalone	*Haliotis kamtschatkana*		IT, ST, KE, RO	PL	IT, ST, KE, RO	IT, ST, KE, RO
Cephalopods	Opal Squid	*Loligo opalescens*	IT, ST	IT, ST, MU, SA, GR, SH, RO		IT, ST	IT, ST
	Neon Flying Squid	*Ommastrephes bartrami*	PE	PE	PE	PE	PE
	Giant Pacific Octopus	*Octopus dofleini*		BE	PL	BE, SE, MU, SA, GR, SH, RO	BE, SE, MU, SA, GR, SH, RO

Commercial echinoderms include sea cucumbers and sea urchins, which occur benthically throughout British Columbia's coastal waters. Sea cucumbers inhabit a range of habitats, including eelgrass beds, mussel beds, and sheltered rocky substrates. Sea urchins are commonly found along rocky shores with various habitat preferences; kelp beds, moderately strong surf, and open waters. Sea urchin depths range from the low tide line to 1157 m (Stocker *et al. eds*. 2001; DFO 2001d; 2001a; Fisheries and Oceans Canada 2002b; Parker 2002; Perry *et al.* 2001; 2002; Perry and Waddell 1999; Rogers and Neifer 2002; Workman 1999).

Breeding season in sea urchins appears to be triggered by environmental factors such as number of days of bright sunshine, phytoplankton blooms, and warm ocean temperatures (Cameron and Fankboner 1986), which may be affected by climate change. Red sea urchins spawn between March and September, green sea urchins between February and March, and purple sea urchins between October and December. Larvae are planktonic for approximately two months prior to their settling on suitable substrate. Juvenile abundance for red sea urchins has been found to be highest where large numbers of adult red sea urchins are present, as the juveniles may sometimes hide from predators beneath the adult spine canopy (Stocker *et al. eds*. 2001). This association is thought to be important in the recruitment success of juveniles to legal harvesting size (Johannessen *et al.* 2005). Green sea urchins are often found with red urchins, though their distribution tends to be patchy. They are thought to be more mobile than red urchins and may make seasonal migrations between deep and shallow waters (Stocker *et al. eds*. 2001). Although fishing for green sea urchins is focused on only a few locations in PNCIMA, they do occur in other areas, and are usually found at depths <20 m. (I. Perry, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4 GROUNDFISH

Our biological understanding of the life histories of many species of groundfish is limited due to their occurrence at depth, even though many are of significant commercial interest. Stock assessment personnel have for the last few years been assembling information on what is known for some species of groundfish in an area roughly equivalent to the PNCIMA region. These data include spatial distribution of commercial catch and catch per unit effort (CPUE, see Figure 1.8), which can identify hot-spots for species aggregations (Johannessen *et al.* 2005). Recent trawl surveys also provide a fishery-independent assessment of groundfish distribution (Map 2.4). Habitat characteristics, such as depth and substrate, appears to be correlated with certain species (e.g., Sinclair *et al.* 2005). Information remains limited for topics which cannot be determined from catch data, such as the location of spawning and rearing grounds, migratory pathways, and critical habitat. For more detailed information, see Appendix G: Groundfish.

2.4.1 Rockfish

There are approximately 40 species of rockfish in BC. In general, rockfish are slow growing and long lived (some over 100 years), taking between five and ten years to mature sexually. The primarily benthic fish are non-migratory, making mostly only localized movements, but some may make seasonal depth migrations. From an ecosystem perspective, considering the many rockfish species and their life stage habitat preferences, the entire coast from subtidal to depths of at least 2000 m could be considered important rockfish habitat (R. Stanley, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Rockfish habitat has thus not been mapped here.

Rockfish are typically grouped into three depth zones: inshore (0-182 m or 0-100 fathoms), shelf (91-182 m or 50-100 fathoms) and slope (>182 m or >100 fathoms) (Table 2.2).

Tables 2.2 – 2.4 provide biological information on species associated with the three rockfish zones listed above. Only commercially important species have been examined in detail in this section due to lack of information on other species. Species unique to the PNCIMA region were noted where applicable; however, most rockfish are distributed throughout the coastal waters of BC (Johannessen *et al.* 2005).

Table 2.2 Commercially important rockfish species (*Sebastes*, *S.*) are listed according to these zones.

Inshore Rockfish		**Shelf rockfish**		**Slope rockfish**	
Tiger	*S. nigrocinctus*	Silvergrey	*S. brevispinis*	Pacific Ocean Perch	*S. alutus*
Yelloweye	*S. ruberrimus*	Canary	*S. pinniger*	Yellowmouth	*S. reedi*
Quillback	*S. maliger*	Yellowtail	*S. flavidus*	Rougheye	*S. aleutianus*
Copper	*S. caurinus*	Widow	*S. entomelas*	Redstripe	*S. proriger*
China	*S. nebulosus*			ShortspineThornyhead	*Sebastolobus alascanus*
				LongspineThornyhead	*Sebastolobus altivelis*

(Bonnet *et al.* 2006)

Inshore Rockfish

In general, inshore species are slow growing, late maturing, long-lived, sedentary as adults, and are associated with specific rocky reef habitats. They mate in the fall and release free-swimming larvae in the early spring. Larvae are pelagic until they settle and generally reside in reefs. Inshore species tend to experience good recruitment every 15-20 years.

Due to declines in the abundance of some inshore rockfish populations, Rockfish Conservation Areas (RCAs) were instated to protect and preserve rockfish biomass (Map 2.5). BC has a total of 89 RCAs covering 2,338 km^2 (Fisheries and Oceans Canada 2004). These protected areas do not prohibit all activities within them.

Table 2.3 Inshore rockfish species (*Sebastes*, *S.*) summary information (sources at end of Table 2.5).

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Yelloweye *S. ruberrimus*	Gulf of Alaska to Baja California.	Shallow waters in the spring, although they are caught mainly in deeper waters. Common around reefs with caves and crevices. 15-366 m.	Mate in fall and spawn in spring.	117	18 yrs (Size Unknown)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Quillback *S. maliger*	Gulf of Alaska to Avila California.	Rocky reefs around caves and crevices, in inlets and shallow rock piles. 9-274 m	Mate in fall and spawn in spring.	76	12 yrs (23-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Copper *S. caurinus*	Kenai Peninsula, Alaska to Baja California.	Offshore rocky reefs and in shallow bays to often >20 m, up to 90 m. Prefer rocky to rock/sand bottoms with irregular bathymetry.	Mate in fall and spawn in spring.	45	8 yrs (41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
China *S. nebulosus*	Prince William Sound, Alaska to San Miguel, California.	Along the bottom of the ocean floor around offshore reefs with crevices and caves. 3-128 m.	Mate in fall and spawn in spring.	u	Age Unknown (28-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Black *S. melanops*	Amchitka Island, Alaska to Huntingbeach California.	Occur in large aggregates around rocky reefs and soft bottom substrates. Midwater habitats usually around kelp or other cover. Occasionally found in offshore open waters. 0-367 m.	Mate in fall and spawn in spring.	u	Females: 11 yrs Males: 10 yrs (36-41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Tiger *S. nigrocinctus*	Prince William Sound, Alaska to Point Buchon, California.	Deep waters near rocky crevices and caves. 24-274 m	Mate in fall and spawn in spring.	u	u	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u

Table 2.4 Slope rockfish species summary information (sources listed at end of Table 2.5).

Species	Distribution	Habitat	Spawn	Life Span (years)	Age at Sexual Maturity or Size at 50 % Maturity	Relevance to PNCIMA Area	Stock Status in PNCIMA Area	
							Abundance	Trend
Yellowmouth *S. reedi*	Gulf of Alaska to northern California. Second most abundant slope rockfish in terms of catch in BC.	100-430 m.	April/May.	70-100	9 yrs 38 cm	Large catches taken from Goose Island and Mitchell's gullies in the QCS.	Average	Expected to decline until next major recruitment occurs.
Rougheye *S. aleutianus*	Japan and Kamchatka Peninsula to Bering Sea and Aleutian Islands, down to southern California.	Prefer boulder fields along the continental slope shelf. 25-2,830 m.	April.	147	Age Unknown Females: 47 cm Males: 45 cm	Significant landings come from Goose Island and Moresby gullies in the QCS.	Low	Uncertain, but thought to remain low for some time.
Shortraker *S. borealis*	Japan, the Okhotsk Sea, and SE Kamchatka to the Bering Sea and Aleutian Islands and down to California.	25-875 m. Larger solitary individuals found on silt or cobble bottoms near boulders.	April..	120	Age Unknown 45 cm	Trawling activity occurs along WCVI. Hook and line activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Not expected to increase in the near future.
Redstripe Rockfish *S. proriger*	Bering Sea to southern California	Areas of high relief and rocky bottoms. 12-425 m.	May-July.	48	Age Unknown 28 cm	Bottom and midwater trawling activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Declining.
Shortspine Thornyheads *Sebastolobus altivelis*	Northern Baja to the Bering Sea to the Commander Islands, north of Japan.	Uniformly distributed along soft sediments, near rocks or other high-relief structures. 90-1460 m. Migrate into deeper waters as they increase in size.	Spawn in spring. Produce jelly egg mass (20,000-450,000 eggs), which float to surface where development and hatching occur. Pelagic for 14-15 months then settle to depths of 100 m and then migrate to deeper waters.	62 (AK) 100*(Cal.)	16 yrs (AK) 28 yrs (Cal.) 23-25 cm	This species represents approx. 90% of catch from the Goose Island, Mitchell's and Moresby gullies in QCS and Hecate Strait.	u	u
Pacific Ocean Perch *S. alutus*	Southern California to the Bering Sea and southwest to the Kurile Islands.	Prefer rocky, high relief substrate, but are commercially found/harvested over cobble substrate. Live at depths of 40-640 m.	Spawn in March/April in the QCS. Juveniles pelagic for 2-3 yrs. Fecundity: 90,000-510,000 eggs.	100	Females: 8 yrs, 35 cm Males: 6-8 yrs, 34 cm	Hecate Strait and QCS dominate fishing areas for perch – mostly in QCS. Three main locations are the Goose Island, Mitchell's and Moresby gullies.	Stable	Slowly declining.

Table 2.5 Shelf rockfish species summary information.

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Widow *S. entomelas*	Southern California to the Gulf of Alaska. Commercial abundance ranges from northern California to central BC. Distribution is difficult to predict.	High relief near edge of continental shelf. 50-375 m.	Spawn late winter or early spring.	58	Females: 14 yrs. Males: 5 yrs. 43 cm	QCS represents a large proportion of coast wide landings. Fishing hot spots include Triangle Island in the winter and Goose Island Bank in the summer.	u	u
Silvergray *S. brevispinis*	Southern California to the Bering Sea. Center of commercial abundance in BC.	High relief near the edge of the continental shelf Commercial fished between 100-375 m.	Mate in spring and spawn mid-summer.	80	Females: 15 yrs. Males: 8 yrs. 38-51 cm	Four stocks in BC, three occur in the PNCIMA region, Hecate Strait, QCS, and WCVI.	abundant in QCS	u
Canary *S. pinniger*	Baja California to the Gulf of Alaska. Center of commercial abundance is northern California to central BC.	High relief areas near the edge of the continental shelf. Around reefs and over soft bottoms. 50-375 m.	Mate in mid-fall and spawn late winter or early spring.	60	Between the ages of 5 and 14 yrs. 58 cm	Two stocks in BC, QCS and WCVI. Most landings come from the central coast of WCVI (60-70 %) and QCS.	u	u
Yellowtail *S. flavidus*	San Diego, California to the Gulf of Alaska. Center of commercial abundance is northern California to northern BC.	Adopts both a near- and off- bottom habitats. Around offshore reefs to depths of 549 m. Have a homing instinct.	Mate in mid-fall and spawn late winter or early spring.	50	Between the ages of 5 and 14 yrs. 36-46 cm	Two stocks, Boundary (southern WCVI to northern Washington, 3C) and Coastal (central WCVI to Alaska, 3D, 5A-5E). Majority of landings come from QCS and south and central WCVI.	Low	Declining

(Fisheries and Oceans Canada 2000b, DFO 1999l, 1999g, 1999h, 1999f, 1999j, 1999e, 1999k, 1999i, 1999a, 1999m, Gotshall 1981; Lamb and Edgell 1986, Stein and Hassler 1989).
u – Information unknown.

2.4.2 Roundfish

Pacific Cod

Pacific cod are a relatively short-lived, fecund species. In the PNCIMA region, Pacific cod densities appear to be highest in the deep troughs in Queen Charlotte Sound, around Goose Island grounds, and southeast Dixon Entrance. They tend to be commercially abundant at depths of 18-130 m but do occur in waters up to 550 m, and prefer sandy or muddy bottoms (Westrheim 1996). Pacific cod exhibit little movement within a given area but do undergo seasonal migrations from shallower waters in the spring and summer to deeper waters in the fall and winter. Spawning occurs once annually between February and March. Eggs are demersal, are slightly adhesive, and are commonly deposited on shell, coarse sand, sandy gravel, muddy sand, and cobble (Westrheim 1996). Hatching occurs after 15-17 days, depending on water temperatures. Larvae are then planktonic and settle near the bottom (at depths of 5-11 m) and incubate for 10-17 days depending on water temperatures. It is during this time that Pacific cod are especially susceptible to environmental changes (Booth 2000). Important spawning and rearing areas are shown in Map 2.6.

Walleye Pollock

Walleye pollock are considered the most abundant fish species in the North Pacific Ocean. In BC, pollock are present throughout the coast. They are semi-demersal and are most abundant along the continental shelf and slope at depths between 100-400 m. However, during various stages of their lifecycle, they may also be found nearshore, in large estuaries, coastal embayments and open ocean basins. Schooling pollock spawn in March and April at depths between 50-300 m and are usually associated with an increase in abundance of Pacific hake (Shaw and McFarlane 1986). Eggs are released into the water, and both planktonic eggs and juveniles appear in the upper water column up to 60 m deep. Schools of juveniles make diel migrations to surface waters at night to feed on plankton and return to deeper waters during the daytime. Juveniles may be found in a variety of habitats including eelgrass beds (over sand and mud substrates), and gravel and cobble bottom types. In addition to the spawning and rearing areas identified during the EBSA process (Map 2.7), past reports have indicated spawning in inlets on east Moresby Island as well as in midwater inlets along Hecate Strait and Queen Charlotte Sound (Shaw and McFarlane 1986).

Pacific Hake

In BC there are two Pacific hake stocks, a non-migratory inshore stock in the Strait of Georgia and a migratory stock offshore of the west coast of Vancouver Island (WCVI), which sometimes extends into PNCIMA. Offshore hake range from southern California to Queen Charlotte Sound with annual migrations into Canadian waters in early spring to late fall (February to November). They are generally found schooling near the bottom or at midwater depths (200-1000 m) over the continental shelf, primarily off of WCVI in Canada. In the past, high levels of biomass have been detected in the PNCIMA region around Brooks Peninsula (Scagel and McFarlane 1995). However, the overall abundance here is generally low compared to numbers off of the WCVI. Significant numbers of hake were observed in PNCIMA in 1998 and 2005, and in 2006 were higher than WCVI (W. Crawford, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2007). The extent to which offshore hake in California move northwards appears to be dependent on water temperatures (specifically the northern extent of warm waters). In El Niño years, larger numbers of hake were observed to migrate into Canadian waters and were found to migrate further north, even as far as Hecate Strait and Dixon Entrance (Map 2.8). An increase in juveniles along the WCVI also suggests that a shift in settlement patterns may also occur during these events (Dorn *et al.* 1999).

Lingcod

Lingcod range from California to Alaska in the eastern Pacific Ocean, centered in BC. They are largely non-migratory and reside in rocky areas at depths of 3-400 m, but are most commonly found between 10-100 m. Lingcod are generally associated with clean waters over rocky substrate, (*i.e.,* where there is an abundance of rocky outcroppings, crevices, caves, or boulders) at shallow depths and high relief bedrock at intermediate depths (LaRiviere 1981; Cass *et al.* 1990; Jamieson and Dixon 2001). They are also commonly associated with 75-100% substrate cover by sessile invertebrates and algae, and with strong currents (up to 4-6 km hr^{-1})(Jamieson and Dixon 2001). In the PNCIMA region, densities appear to be highest in northern Moresby Trough, the southern edge of Dixon Entrance, and around Goose Island Bank.

Mating season starts with the onset of adult males migrating to near shore in October (prior to female migration) to establish nesting sites. Nests may be found intertidally down to 100 m depth, but are most commonly found between 5-25 m in rock crevices or on ledges where there is a strong current to oxygenate the egg masses. Spawning occurs annually from December to March, during which time females migrate nearshore to deposit egg masses in the nesting sites previously established by the males. Males then fertilize the egg mass and remain behind to guard the nest until the eggs hatch in early March to late April. Females return to deeper waters shortly after spawning. Once hatched, larvae remain planktonic for 6-8 weeks, reaching approximately 4-5 cm. Larvae settle onto bottom substrates in inshore waters, usually near kelp or eelgrass beds. Juvenile rearing habitat is eelgrass beds and sandy/flat bottom habitat from 0-75 m (J. King, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Juveniles, unlike adults, are often found on flat substrates in shallower waters, and later move to areas of high relief and rockiness as they mature. The benthic dispersal of lingcod is believed to be limited, as lingcod have been found to colonize and recruit in localized areas. An area of the northern coast of Vancouver Island is known spawning and rearing habitat (Map 2.9); other areas are not well known (J. Fargo, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Sablefish

Genetically, sablefish appear to represent a single stock, but movement of adults is limited. In BC, two populations, Alaskan (north) and west coast (south), are separately managed, and these have been delineated based on varying recruitment and growth differences. The distribution of adult sablefish is depth dependent, with older individuals and males most abundant at greater depths (Haist *et al.* 1999).

Spawning occurs both within and outside of the PNCIMA region along the continental slope at roughly 1000 m or greater depths, between January and March. In April/May, larvae rise to surface waters over the shelf and then migrate inshore for approximately 6 months. Young sablefish rear in nearshore waters and shelf habitats until 2-5 years of age, at which point they migrate back to offshore waters and into the fishing grounds (Fisheries and Oceans Canada 2002c).

Juveniles are highly mobile and can move between nursery areas in Hecate Strait to the Gulf of Alaska and the Bering Sea. Spawners, larvae and juveniles can be found in almost all areas of PNCIMA, depending on the strength of recruitment (R.A. Kronlund, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4.3 Flatfish

Sole and Flounder

Dover sole: Dover sole are a deep-water species commonly found along muddy bottoms in deep troughs and are generally found in deeper waters during the winter than in the summer (Sinclair 2002; Fargo and Kronlund 1997). In Hecate Strait they spawn annually in deep waters off the west coast of the Queen Charlotte Islands during the late fall and winter at depths between 800-1000 m (Map 2.10) (DFO 1999b; Westrheim *et al.* 1992). Larvae undergo a prolonged pelagic phase offshore in surface waters along the continental shelf for up to 2 years, before they gradually move into deeper waters along the slope as they grow and reach sexual maturity (Fargo and Kronlund 1997; Jacobson and Hunter 1993). As adults, females are generally found in deeper waters than males, and larger Dover soles are generally found deepest, where oxygen concentrations are lowest (Jacobson and Hunter 1993).

English sole: English sole are found between 5-150 m depth, preferring shelf waters and, unlike other flatfish species, are not generally found in deeper waters during the winter months (Sinclair 2002). English sole are associated with sandy-mud substrates and show preference for water temperatures between 7-10 °C (Fargo *et al.* 2000).

English sole spawn annually between September and March with peak spawning activity occurring in October/November. Older individuals tend to spawn latest in the fall. They exhibit extreme sexual dimorphism and are non-intermittent spawners (Fargo *et al.* 2000). Fertilized eggs hatch after 6-10 days, depending on water temperatures and salinity. Pelagic larvae drift for 6-10 weeks, many in shallow (0-20 m) bays or estuaries, where they stay until they reach approximately 2 cm. One of the primary English sole nurseries in BC is in the nearshore shallow waters off the east coast of Graham Island (Map 2.10) (Fargo *et al.* 2000). After metamorphosis is completed, individuals settle to the bottom and continue to develop. Between the ages of two and three, they slowly migrate into deeper waters and, by four years of age, they are mixed with adults.

Petrale sole: Petrale sole are found at depths from 18-750 m in areas with sandy substrate (Booth 2000; Eschmeyer and Herald 1983). Petrale make extensive seasonal movements. They are generally found in deeper waters during spawning in the winter, and in shallower waters, particularly around Goose Island, during feeding in the summer (Sinclair 2002; Forrester 1969).

Petrale spawn annually during the winter months off the WCVI and the northern tip of the Queen Charlotte Islands (Map 2.10). Females release eggs into surface waters where they are fertilized and float freely during incubation. After approximately 8 days (varying with water temperature and salinity), the eggs hatch and the larvae remain planktonic, drifting in ocean currents until they reach nursing grounds. Key nursery grounds in the Hecate Strait and Queen Charlotte Sound area are along the eastern boundary of Goose Island Bank and to a lesser extent along Cape Scott (Cook) Bank, Horseshoe Grounds, and "Ole Spot" in area 5C (Map 2.10) (Ketchen and Forrester 1966).

Rex sole: Rex sole are usually found in sand or mud bottom substrates at depths of 18-640 m. The catch distribution, which is higher on the shelf in the troughs and around the edges of banks, suggests they are most abundant at about 60 m (Johannessen *et al.* 2005). According to Hosie (1975), spawning occurs between January and June along the offshore area of Oregon, with peak activity in March/April. Spawning location varies by year.

Rock sole: Rock sole adults show little preference among substrates, although in BC they are most abundant over gravel substrates at depths between 18-55 m (Fargo *et al.* 2000; Booth 2000). Rock sole are essentially a shallow water species (5-80 m) and so adult populations may be separated by the deep troughs found in Queen Charlotte Sound and Hecate Strait (Sinclair 2002; Fargo *et al.* 2000). Rock sole are non-intermittent spawners. They spawn annually, usually at 20-40 m depths, with peak spawning occurring in March/April. Rock sole have separate localized spawning and summer feeding areas. The primary spawning area is located off Cumshewa Inlet near east Moresby Island (Map 2.10). An important nursery area is around Reef Island just south of Cumshewa Inlet (Strong *et al.* 2002). After spawning, adults migrate to feeding grounds in central Hecate Strait. Fertilised eggs are demersal and adhesive, hatching after approximately 10-15 days (Ketchen 1982). Larvae exhibit diel movement and are commonly found in waters between 5-10 m deep during the day, when they feed on copepod nauplii, and at around 30 m depth at night. Wind and tidal currents transport larvae until they settle to the ocean bottom at about 2 cm length. For the first year, juveniles remain in waters between 5-20 m deep, and by 2-3 years of age, have moved to waters 20-80 m deep.

Arrowtooth flounder: Arrowtooth flounder juveniles occur in waters along the continental shelf until an age of 4, after which they migrate into deeper waters to join the adults along the continental slope. Adults are generally found in areas where there is coarse sand substrate, whereas juveniles are often associated with sand or mud substrates. Arrowtooth flounder typically inhabit waters 50-900 m deep and show preference for bottom temperatures of 7-8 °C. They spawn in the fall and winter months in waters ≥350

m. Their eggs are pelagic; incubation is 3-4 weeks. Larvae are planktonic for 4 weeks before settling as juveniles. As with many other flatfish species, arrowtooth flounder migrate seasonally from deep, winter spawning grounds to shallow, summer feeding grounds. Important spawning and feeding areas in the PNCIMA region have not been identified.

Pacific Halibut

Pacific halibut are commonly found throughout BC's waters along the continental shelf and slope from relatively shallow waters to at least 1000 m (Carl 1971). Mature fish may undergo extensive movement (as far as 3200 km); however, most tend to stay on the same grounds and make only seasonal migrations from shallow feeding areas in the spring to deeper spawning grounds in the winter (Fisheries and Oceans Canada 2002a; Carl 1971). Halibut spawn in waters along the continental shelf at depths between 180-450 m during the winter (November to March; Map 2.11). The PNCIMA region has some locally important spawning grounds including around the Goose Group, around Cape St. James and areas in northern Hecate Strait and Dixon Entrance (Map 2.11) (Fisheries and Oceans Canada 2002a; Carl 1971). Incubation occurs for 15-20 days as eggs rise to the surface. Larvae develop and may be transported by ocean currents great distances in a counter-clockwise direction around the Northeast Pacific Ocean (International Pacific Halibut Commission 1987). Young fish then settle to the ocean bottom in shallow feeding areas before they migrate back into more southerly and easterly waters at 2-3 years of age.

2.5 PELAGIC FISHES

2.5.1 Herring

Pacific herring spawning migrations move from offshore feeding grounds (west coast of Vancouver Island and Hecate Strait in the north) to the inshore spawning grounds during October to December. Herring congregate in large schools over the winter awaiting gonad maturation (Hay 1985; Fisheries and Oceans Canada 1994; Haegele and Schweigert 1985). In BC, herring spawn in late winter, from February to as late as July, with the majority of spawning occurring in March from the high tide line down to 20 m depth (Fisheries and Oceans Canada 1994), although some spawning can be as deep as 60 m. Spawn deposition occurs in high-energy environments on both bottom substrate and vegetation. Temperature and salinity are important in determining when and where herring spawning occurs. Eggs are generally tolerant to temperatures ranging from 5-15 °C and a salinity range of 3-33‰ (Haegele and Schweigert 1985). Eggs hatch in 10-21 days, and larvae concentrate in the surface layer near shore, aggregated by surface currents. Beginning in the late larval stage, herring undergo a diurnal migration, descending to deep water during the day, and rising to the surface at night. Migration of juvenile herring begins in some areas in the fall of their first year and in other areas not until the following summer. Adults are most commonly found in deeper waters (around 100 m). Important areas for herring were identified during the EBSA process; the life history function associated with each area is identified on Map 2.12. Spawning beds from digitized archived surveys for the years 1930-2002 are also shown (McCarter *et al.* 2005).

2.5.2 Eulachon

Major eulachon spawning and larval rearing areas are shown in Map 2.13. Eulachon summer feeding areas are much more extensive than the areas identified during the EBSA process and shown on Map 2.13. Additional areas include: the offshore banks immediately SW and W of Calvert Island (Calvert Island and Pearl Rock Ground) where the eulachon bycatch in shrimp fishing was severe in the late 1990's; the Cape Scott ground; the SE edge and NE corner of the Goose Island bank; the SE edge of Middle Bank (North Bank); the entire 50-100 fathom edge from Rose Spit, Two Peaks, White Rocks, Butterworth edge, Bonilla Island down to the Horseshoe ground and SE to Cape St. James; and the entire Chatham Sound. More information on pelagic species can be found in Appendix H: Pelagic Fishes.

2.6 MARINE MAMMALS AND TURTLES

2.6.1 Cetaceans

For most cetaceans, there is limited knowledge of habitat use within PNCIMA. Canada's Pacific waters are a year round home for some species, while part of annual migration routes or summer feeding grounds for others. It is not clear how important PNCIMA is to the health and stability of cetaceans overall, due to limited data for most species regarding their distribution and their habitat use. Spatial data on cetaceans are being compiled, largely from opportunistic sightings, but also from historical whaling records and habitat modeling. These data sets have been used to produce maps with high levels of uncertainty. Life history functions associated with some areas are identified for gray (Map 2.14), humpback (Map 2.15), and northern resident killer whales (Map 2.16). Important habitat for northern resident killer whales has been identified (Map 2.16), while potential critical habitat for killer whales is still being assessed (Ford 2006). Areas of importance for blue whales (Map 2.17), fin whales (Map 2.18), sei whales (Map 2.19), and sperm whales (Map 2.20), have been identified in the EBSA process (see also Appendix J: Marine Mammals).

2.6.2 Pinnipeds

Steller sea lions and harbour seals remain in BC waters year round. BC waters are also a major migration route and provide vital feeding grounds for California sea lions, northern fur seals and northern elephant seals (Johannessen *et al.* 2005). The PNCIMA region includes all of BC's Steller sea lions rookeries (Map 2.21). Cape St. James and the Scott Islands are critical areas for Steller sea lions. Important areas for feeding and foraging for northern fur seals have also been identified (Map 2.22).

2.6.3 Sea Otters

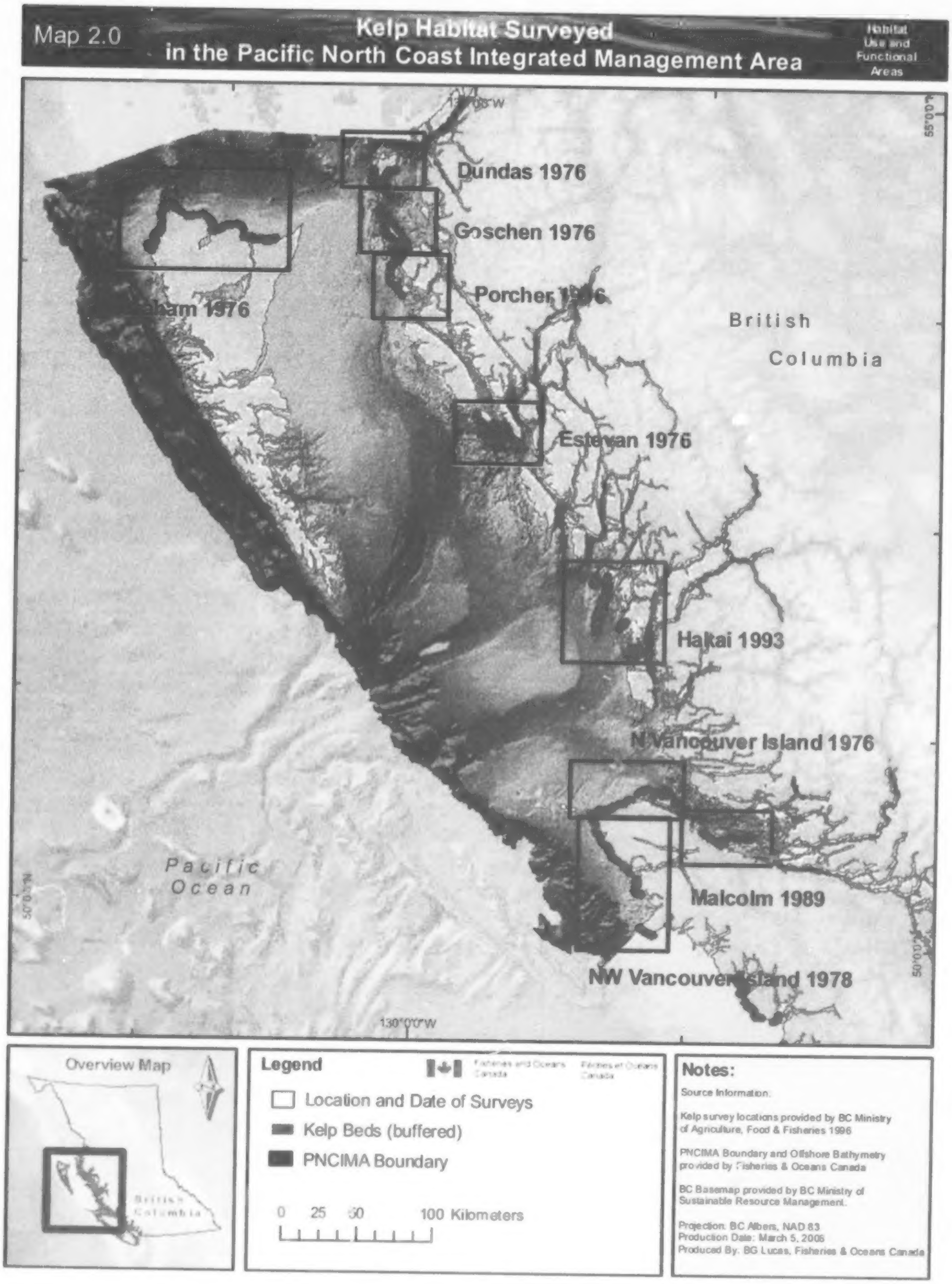
Sea otters have a small population with limited range in PNCIMA (Map 2.23). Their typical habitat is shallow (<40 m), nearshore areas (within 1-2 km of shore) (Reidman and Estes 1990). Kelp beds are important habitat for resting and foraging. Clam beds also provide valuable foraging habitat.

2.6.4 Reptiles

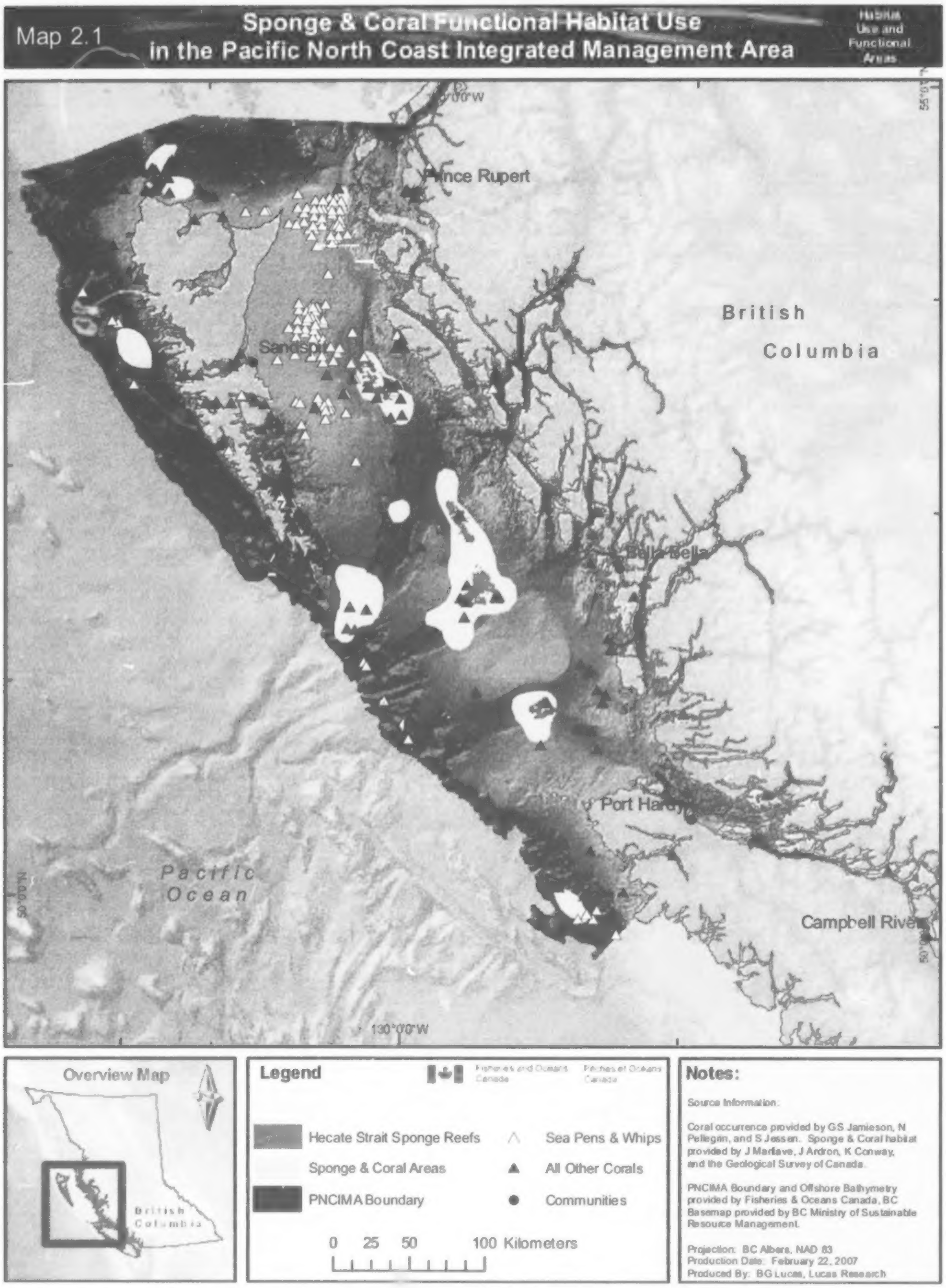
Leatherback turtles nest on beaches in tropical waters, and make long migrations to their feeding areas that include BC waters. The very limited knowledge of leatherback distribution in BC is from anecdotal reports, opportunistic sightings, and recent cetacean/sea turtle surveys. Sightings within PNCIMA are located on Map 2.24, along with important feeding areas.

2.7 ACKNOWLEDGEMENTS

We would like to acknowledge all the authors of the appendices to this Ecosystem Overview and of the Biophysical Overview Report for PNCIMA (Johannessen *et al.* 2005) for providing the detailed information on which some of this chapter is based. We thank Cathryn Clarke for providing the first draft EBSA maps and report. Cathryn Clarke, Aiden Ryan, and Dwight McCullough assisted with GIS technicalities. Stacey Verrin provided technical editing and helpful suggestions. This chapter was improved by the constructive comments of reviewers.


Map 2.0
Kelp Habitat Surveyed
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Dundas 1976
Goschen 1976
Porcher 1976
aham 1976
British Columbia
Estevan 1976
Hakai 1993
N Vancouver Island 1976
Malcolm 1989
NW Vancouver Island 1978
Pacific Ocean
130°0'0"W
55°0'0"N
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
☐ Location and Date of Surveys
▬ Kelp Beds (buffered)
■ PNCIMA Boundary
0 25 50 100 Kilometers
Notes:
Source Information:
Kelp survey locations provided by BC Ministry of Agriculture, Food & Fisheries 1996
PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: March 5, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.0 Kelp habitat surveyed in PNCIMA (data from BC MAFF 1996).


Map 2.1
Sponge & Coral Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Hecate Strait Sponge Reefs
Sponge & Coral Areas
PNCIMA Boundary
Sea Pens & Whips
All Other Corals
Communities
0
25
50
100 Kilometers
Notes:

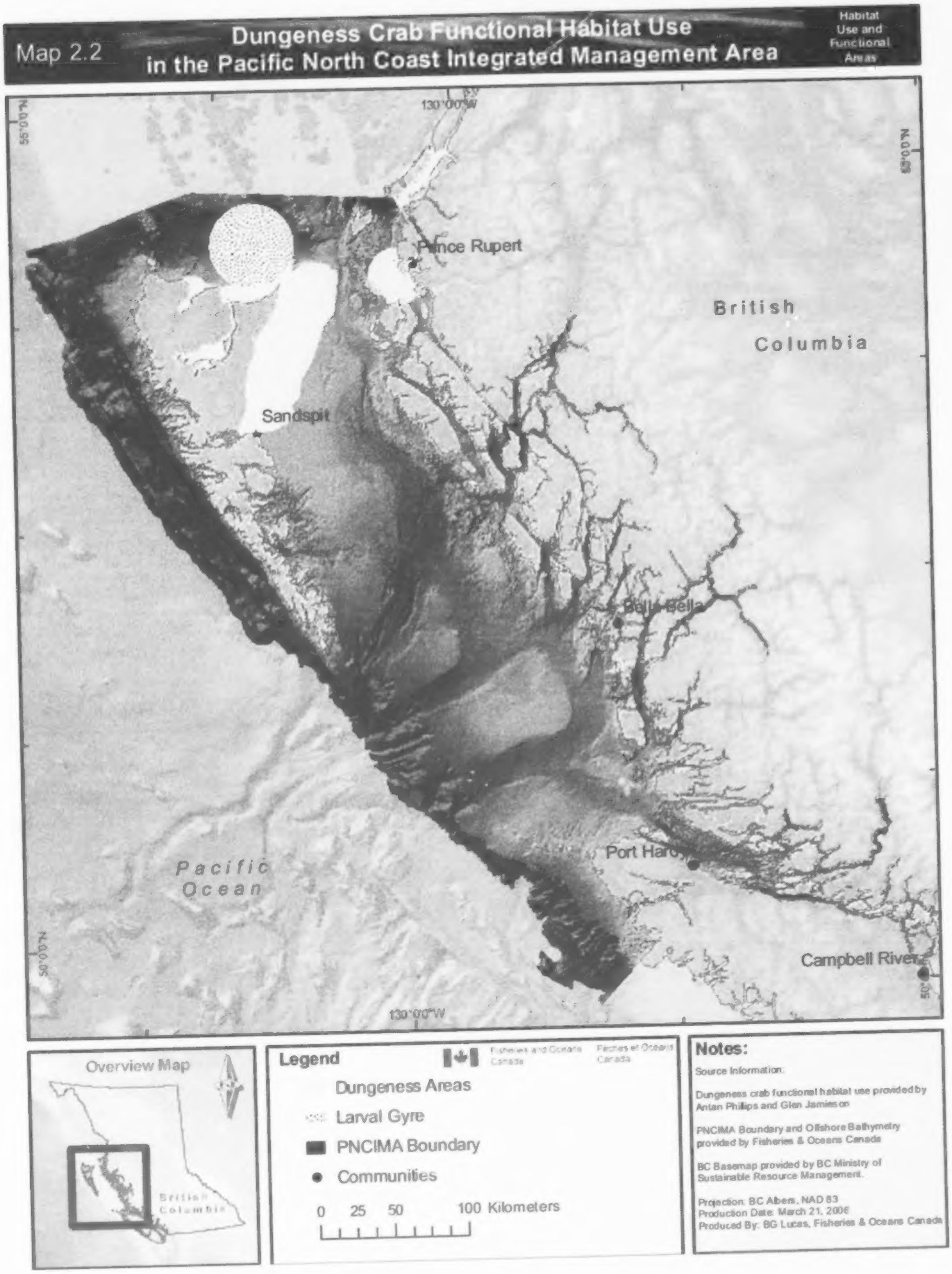
Source Information:

Coral occurrence provided by GS Jamieson, N Pellegrin, and S Jessen. Sponge & Coral habitat provided by J Marliave, J Ardron, K Conway, and the Geological Survey of Canada.

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada, BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.1 Sponge and coral functional habitat use in PNCIMA.


Map 2.2
Dungeness Crab Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
53°0'0"N
50°0'0"N
50°
Prince Rupert
Sandspit
British Columbia
Bella Bella
Port Hardy
Campbell River
Pacific Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Dungeness Areas
Larval Gyre
PNCIMA Boundary
Communities
0 25 50 100 Kilometers

Notes:

Source Information:

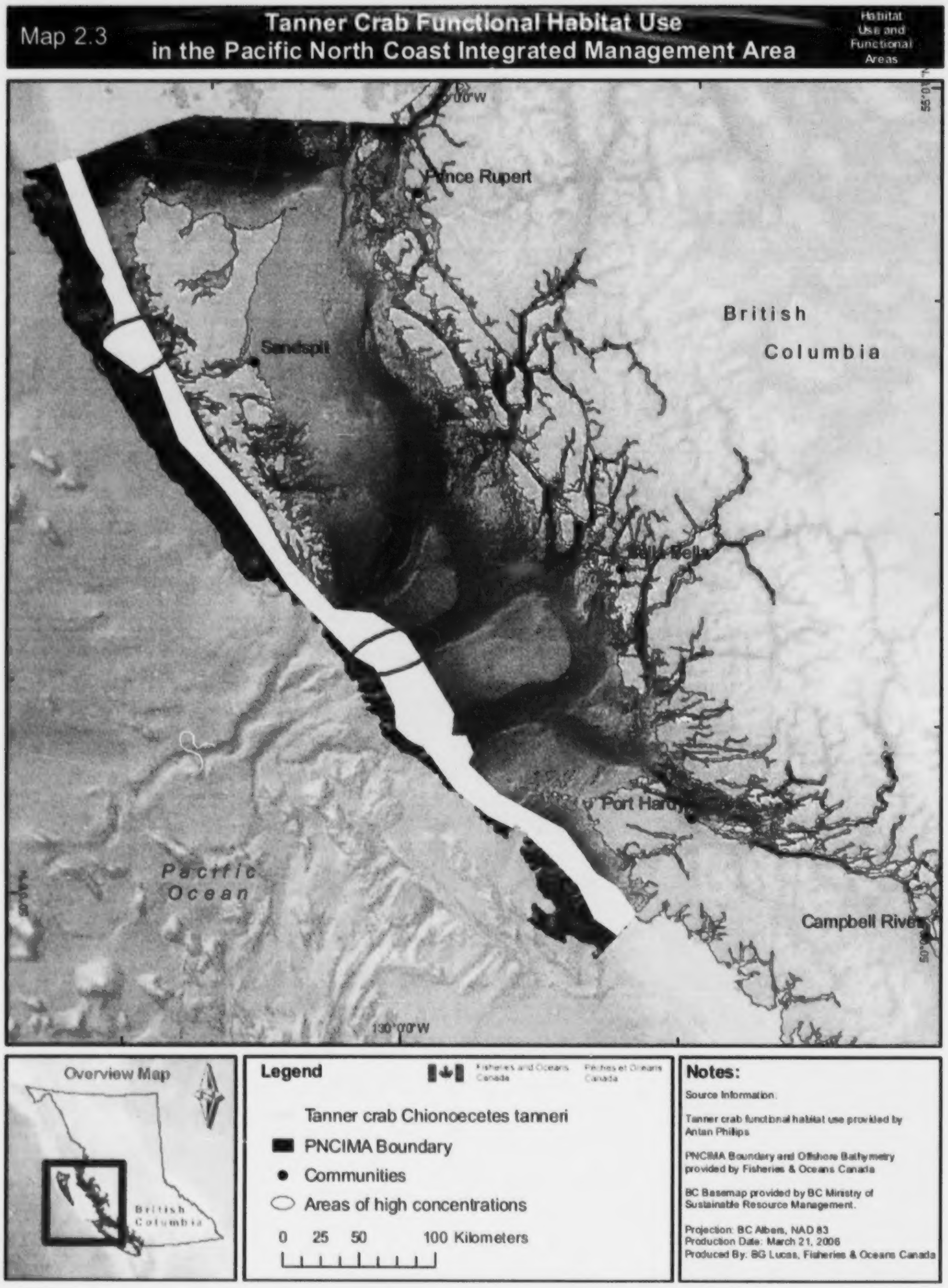
Dungeness crab functional habitat use provided by Antan Phillips and Glen Jamieson

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

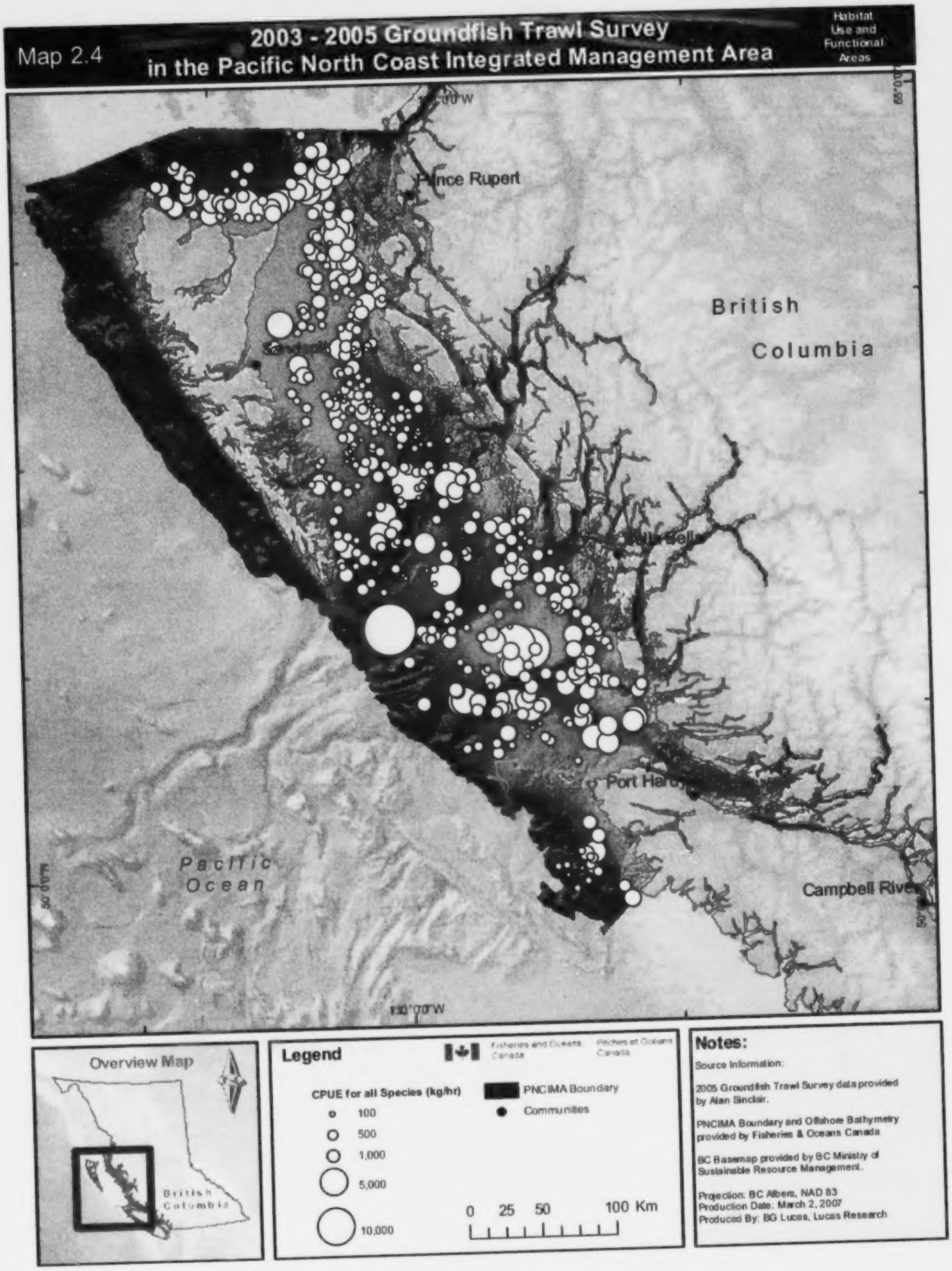
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 21, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.2 Dungeness crab functional habitat use in PNCIMA.


Map 2.3
Tanner Crab Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
Bella Bella
Port Hardy
Campbell River
British Columbia
Pacific Ocean
130°00'W
55°00'N
50°00'N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Tanner crab Chionoecetes tanneri
▬ PNCIMA Boundary
● Communities
○ Areas of high concentrations
0 25 50 100 Kilometers
Notes:
Source Information:
Tanner crab functional habitat use provided by Antan Philips
PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: March 21, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.3 Tanner crab functional habitat use in PNCIMA.


Map 2.4
2003 - 2005 Groundfish Trawl Survey
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°00'W
55°0'0"N
50°0'0"N
Prince Rupert
Sandspit
Bella Bella
Port Hardy
Campbell River
British Columbia
Pacific Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
CPUE for all Species (kg/hr)
100
500
1,000
5,000
10,000
PNCIMA Boundary
Communities
0 25 50 100 Km

Notes:

Source Information:

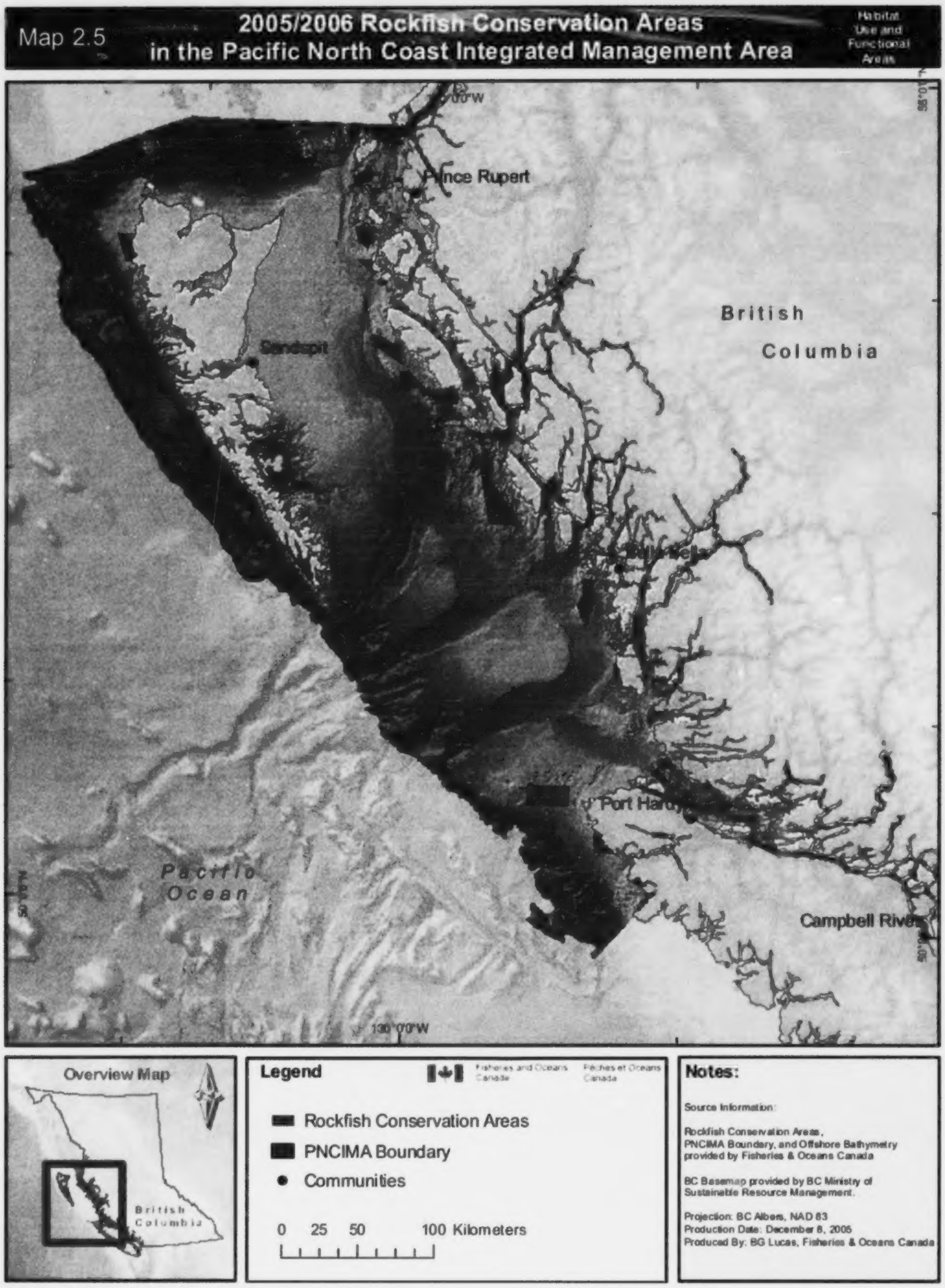
2005 Groundfish Trawl Survey data provided by Alan Sinclair.

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

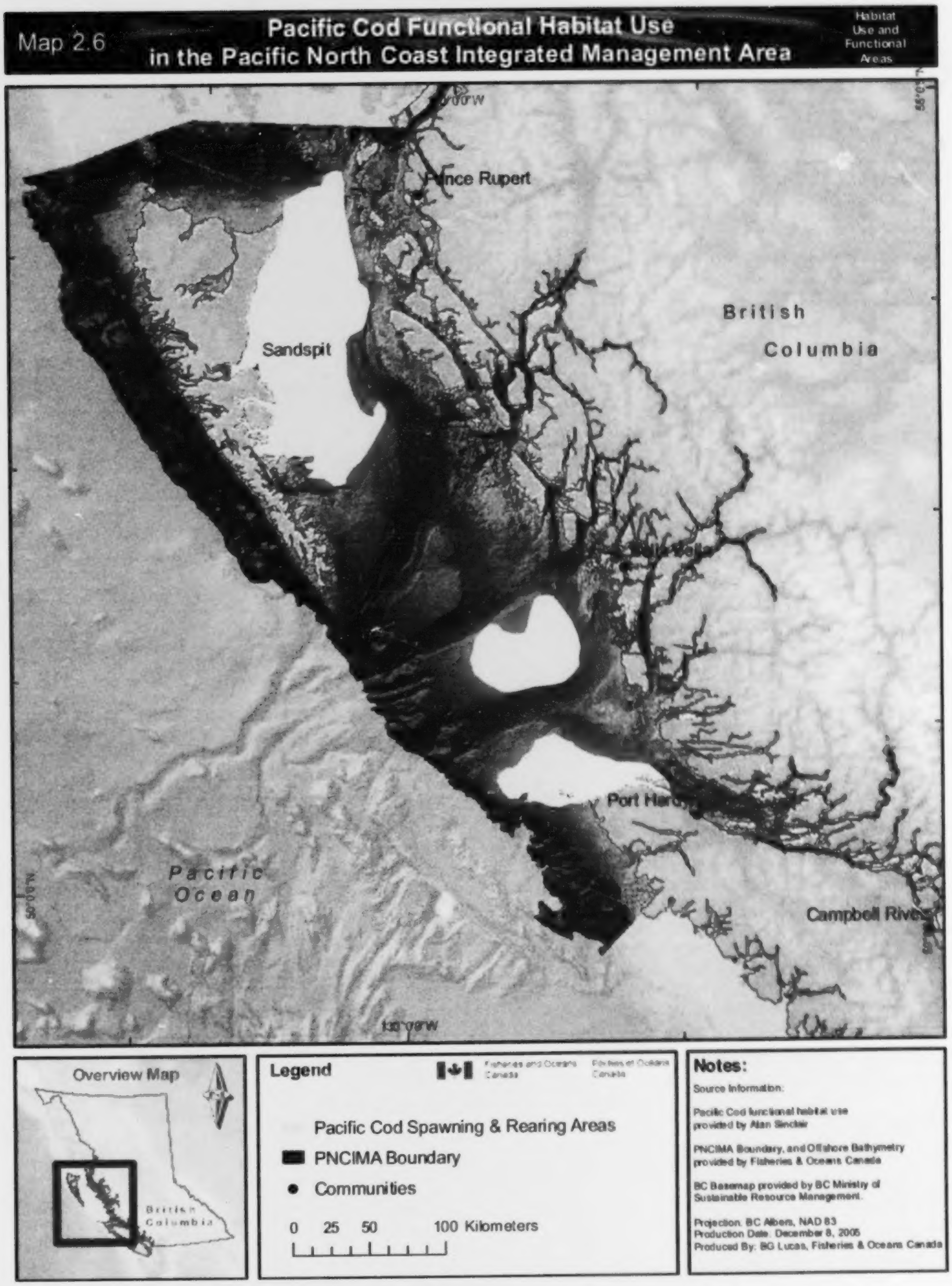
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 2, 2007
Produced By: BG Lucas, Lucas Research

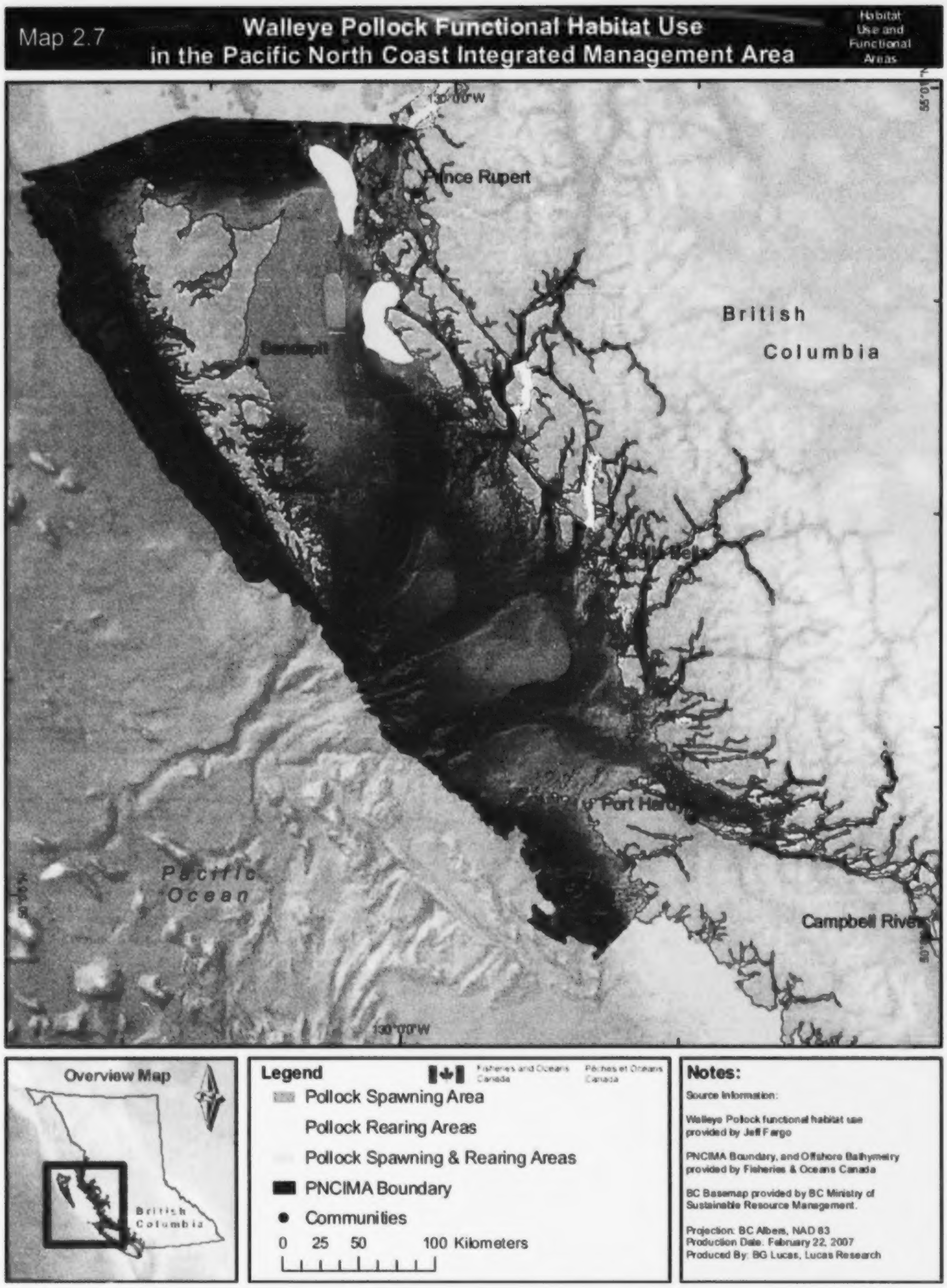
Map 2.4 Catch per unit effort (CPUE) for all species in the 2003-2005 groundfish trawl surveys in PNCIMA (A. Sinclair, unpublished data).


Map 2.5
2005/2006 Rockfish Conservation Areas in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British Columbia
Port Hardy
Campbell River
Pacific Ocean
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Rockfish Conservation Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Rockfish Conservation Areas, PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

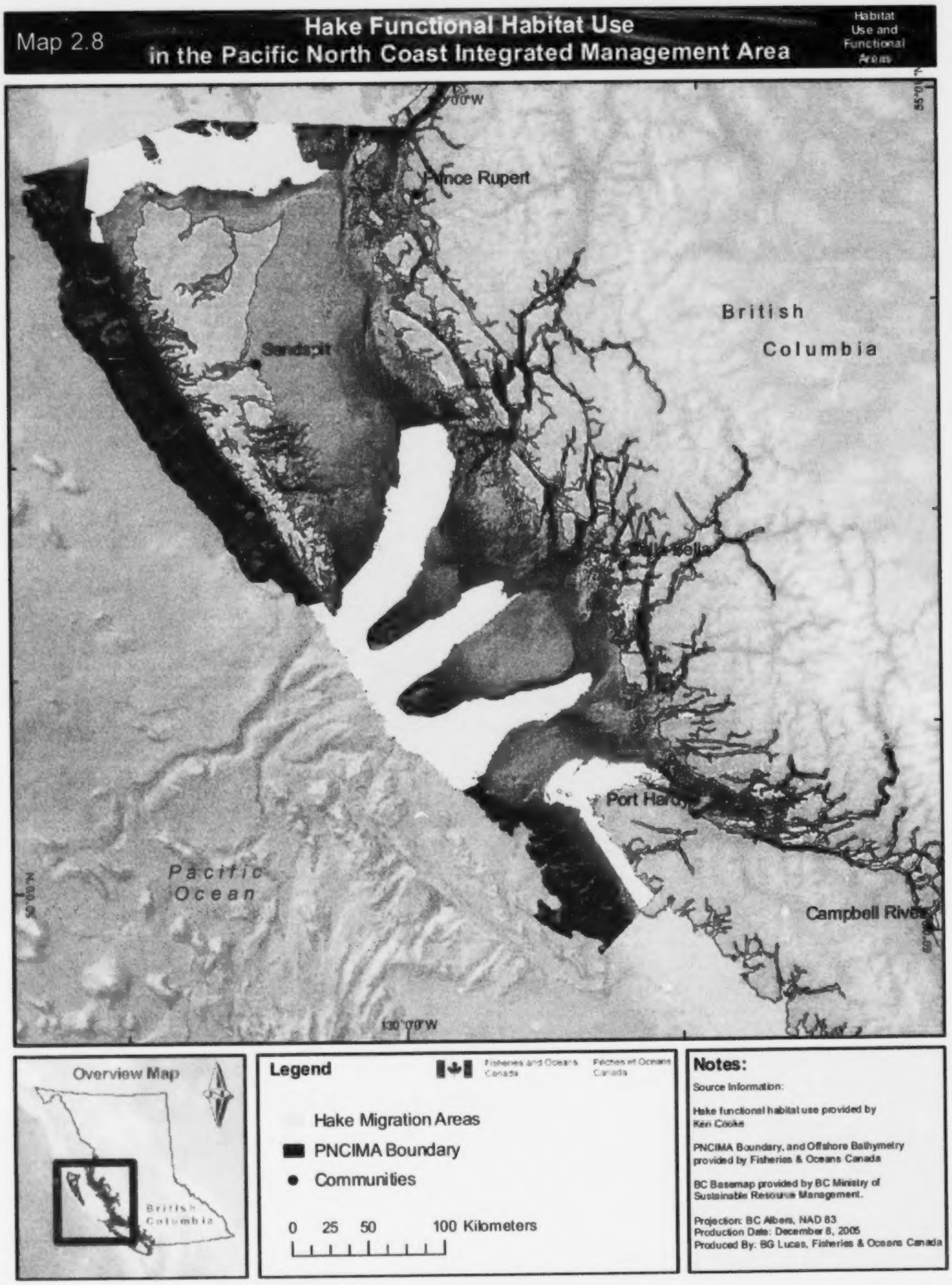
Map 2.5 2005/2006 rockfish conservation areas.


Map 2.6
Pacific Cod Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
55°0'0"N
Prince Rupert
Sandspit
British Columbia
Port Hardy
Campbell Rive
Pacific Ocean
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Pacific Cod Spawning & Rearing Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source information:
Pacific Cod functional habitat use provided by Alan Sinclair
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

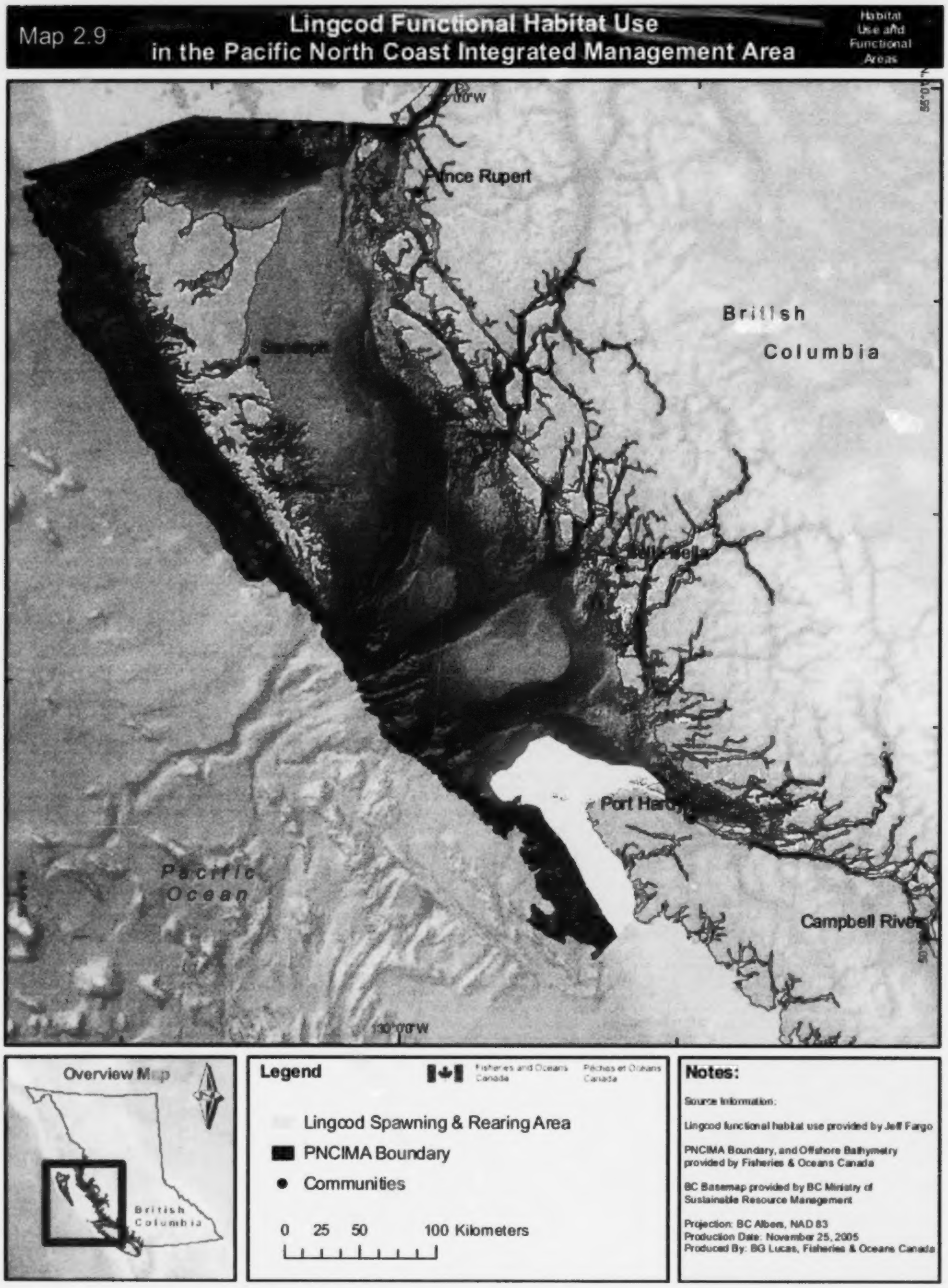
Map 2.6 Pacific cod functional habitat use in PNCIMA.


Map 2.7
Walleye Pollock Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
Prince Rupert
Sandspit
British Columbia
Port Hardy
Campbell River
Pacific Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
▨ Pollock Spawning Area
Pollock Rearing Areas
Pollock Spawning & Rearing Areas
■ PNCIMA Boundary
● Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Walleye Pollock functional habitat use provided by Jeff Fargo
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

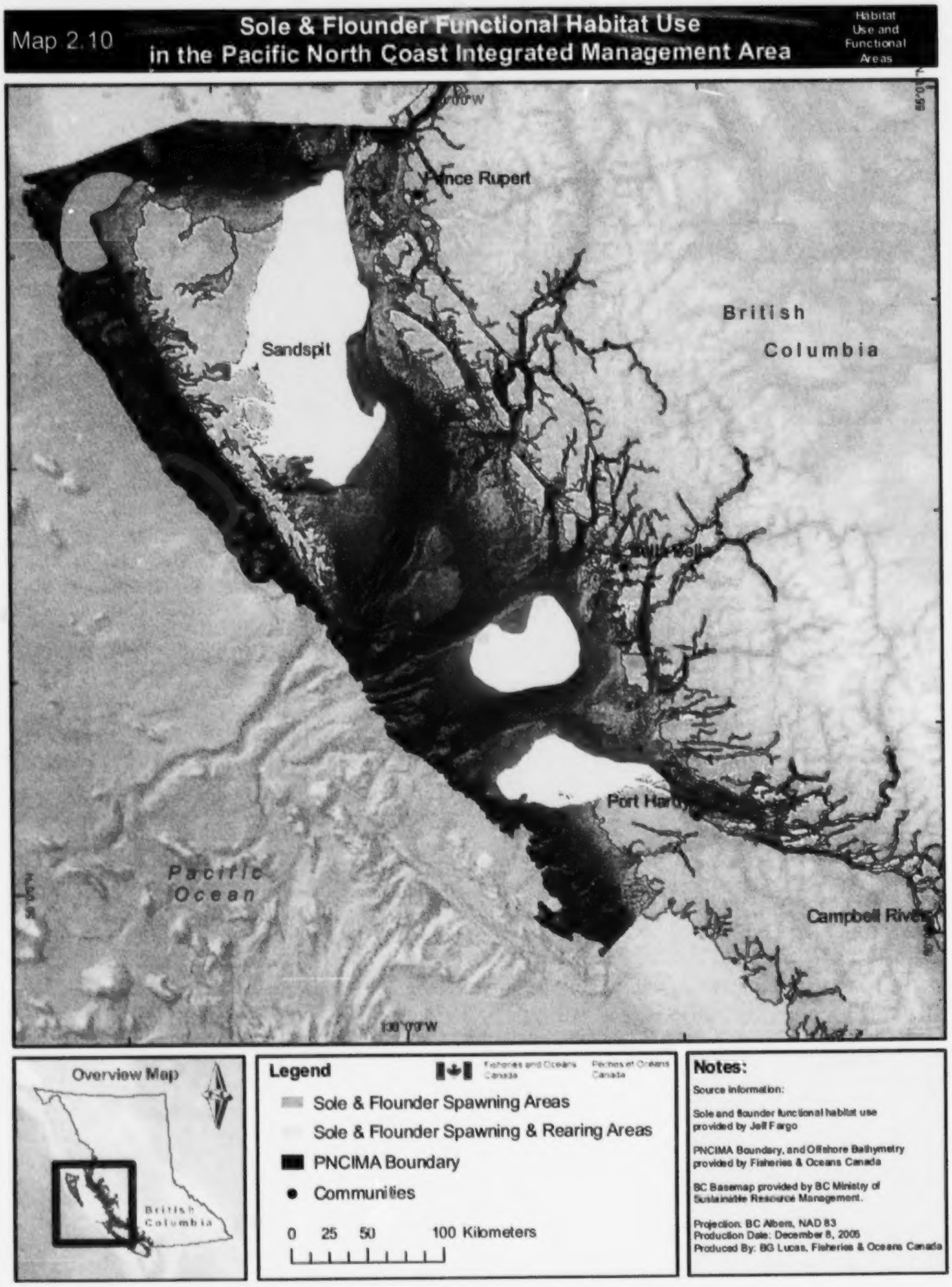
Map 2.7 Walleye pollock functional habitat use in PNCIMA.


Map 2.8
Hake Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British Columbia
Bella Bella
Port Hardy
Campbell River
Pacific Ocean
130°0'0"W
55°0'0"N
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Hake Migration Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Hake functional habitat use provided by Ken Cooke
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

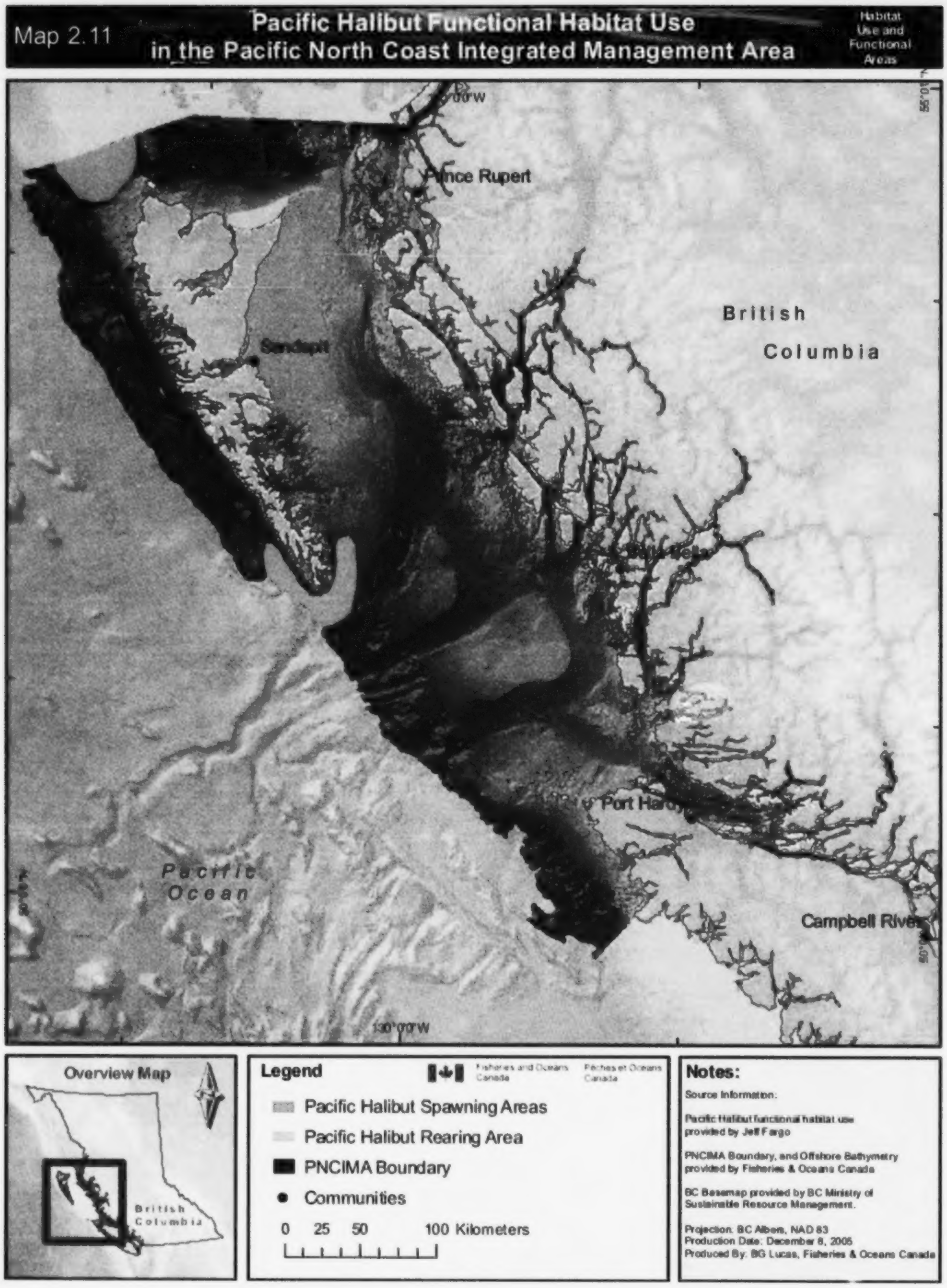
Map 2.8 Hake functional habitat use in PNCIMA.


Map 2.9
Lingcod Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat
Use and
Functional
Areas
130°00'W
55°0'0"N
Prince Rupert
British
Columbia
Port Hardy
Campbell Rive
Pacific
Ocean
130°00'W
Overview Map
British
Columbia
Legend
Fisheries and Oceans
Canada
Pêches et Océans
Canada
Lingcod Spawning & Rearing Area
PNCIMA Boundary
Communities
0
25
50
100 Kilometers
Notes:
Source Information:
Lingcod functional habitat use provided by Jeff Fargo
PNCIMA Boundary, and Offshore Bathymetry
provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of
Sustainable Resource Management
Projection: BC Albers, NAD 83
Production Date: November 25, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.9 Lingcod functional habitat use in PNCIMA.


Map 2.10
Sole & Flounder Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
130°0'0"W
55°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Sole & Flounder Spawning Areas
Sole & Flounder Spawning & Rearing Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source information:
Sole and flounder functional habitat use provided by Jeff Fargo
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.10 Sole and flounder functional habitat use in PNCIMA.


Map 2.11
Pacific Halibut Functional Habitat Use in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°00'W
55°0'N
50°0'N
Prince Rupert
Sandspit
Port Hardy
Campbell River
British Columbia
Pacific Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
▨ Pacific Halibut Spawning Areas
▨ Pacific Halibut Rearing Area
■ PNCIMA Boundary
● Communities
0 25 50 100 Kilometers

Notes:

Source Information:

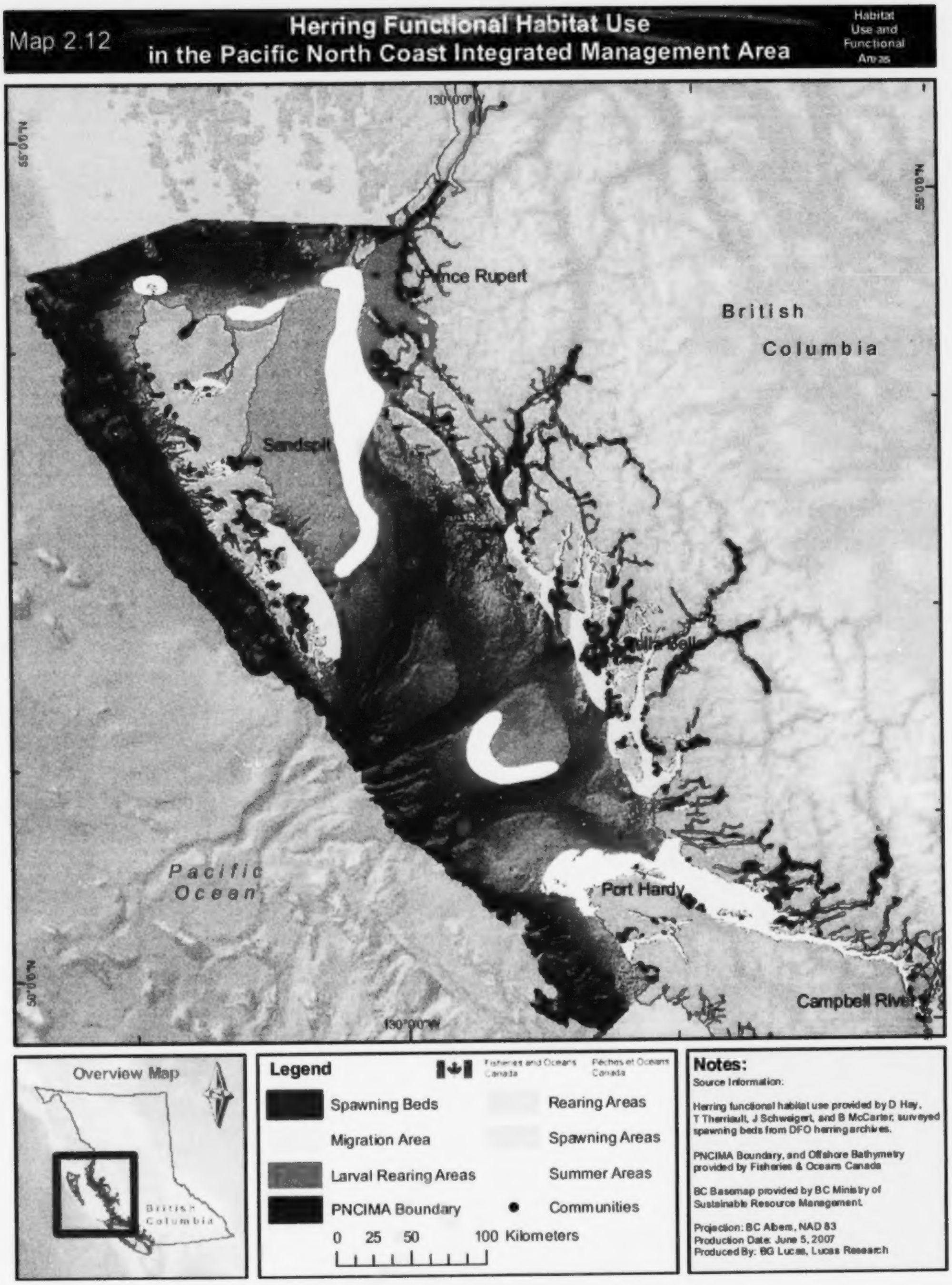
Pacific Halibut functional habitat use provided by Jeff Fargo

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: December 8, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.11 Pacific halibut functional habitat use in PNCIMA.


Map 2.12
Herring Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
55°0'0"N
Prince Rupert
British Columbia
Sandspit
Bella Bella
Pacific Ocean
Port Hardy
Campbell River
50°0'0"N
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Spawning Beds
Migration Area
Larval Rearing Areas
PNCIMA Boundary
Rearing Areas
Spawning Areas
Summer Areas
Communities
0 25 50 100 Kilometers

Notes:

Source Information:

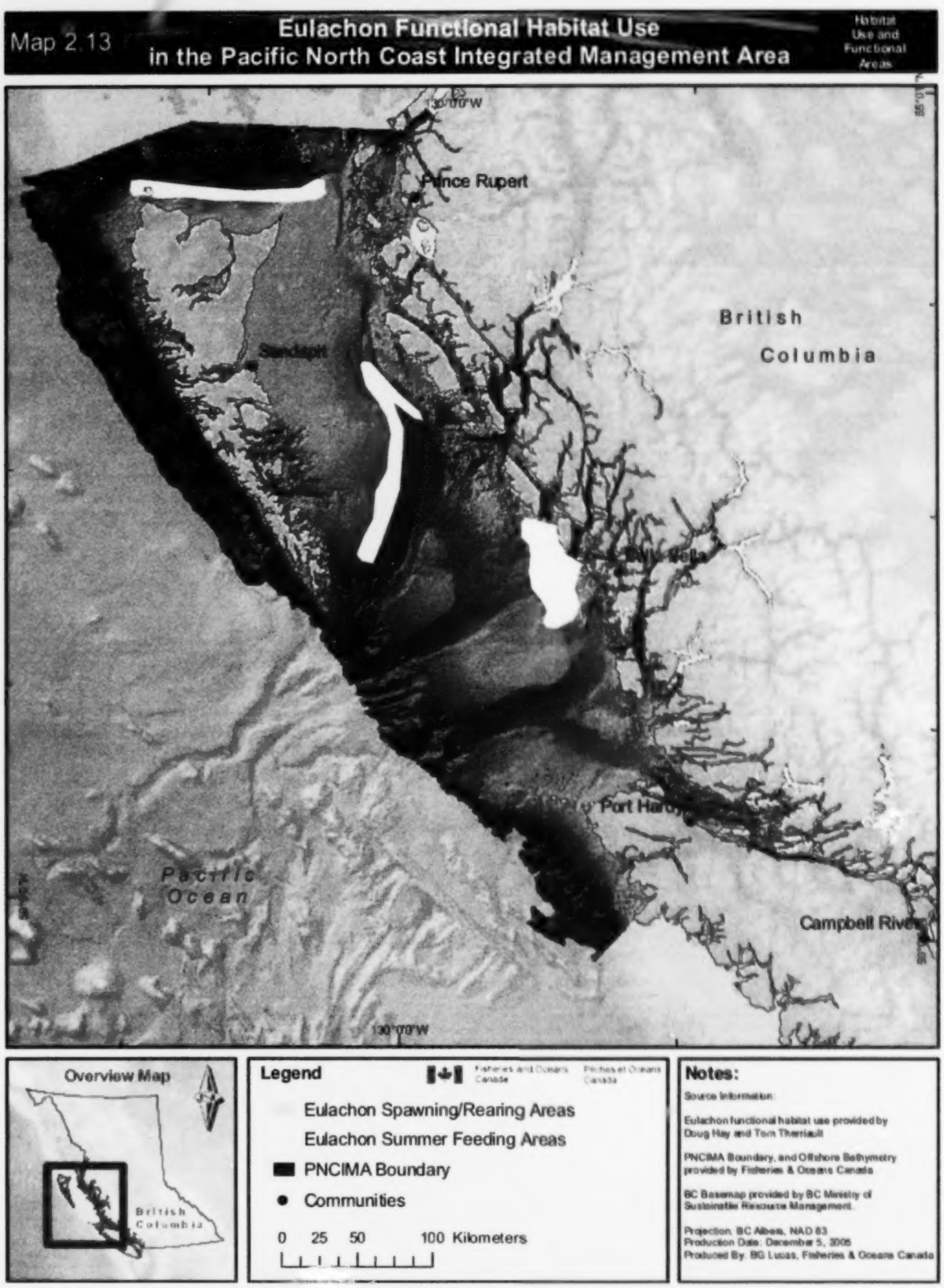
Herring functional habitat use provided by D Hay, T Therriault, J Schweigert, and B McCarter, surveyed spawning beds from DFO herring archives.

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

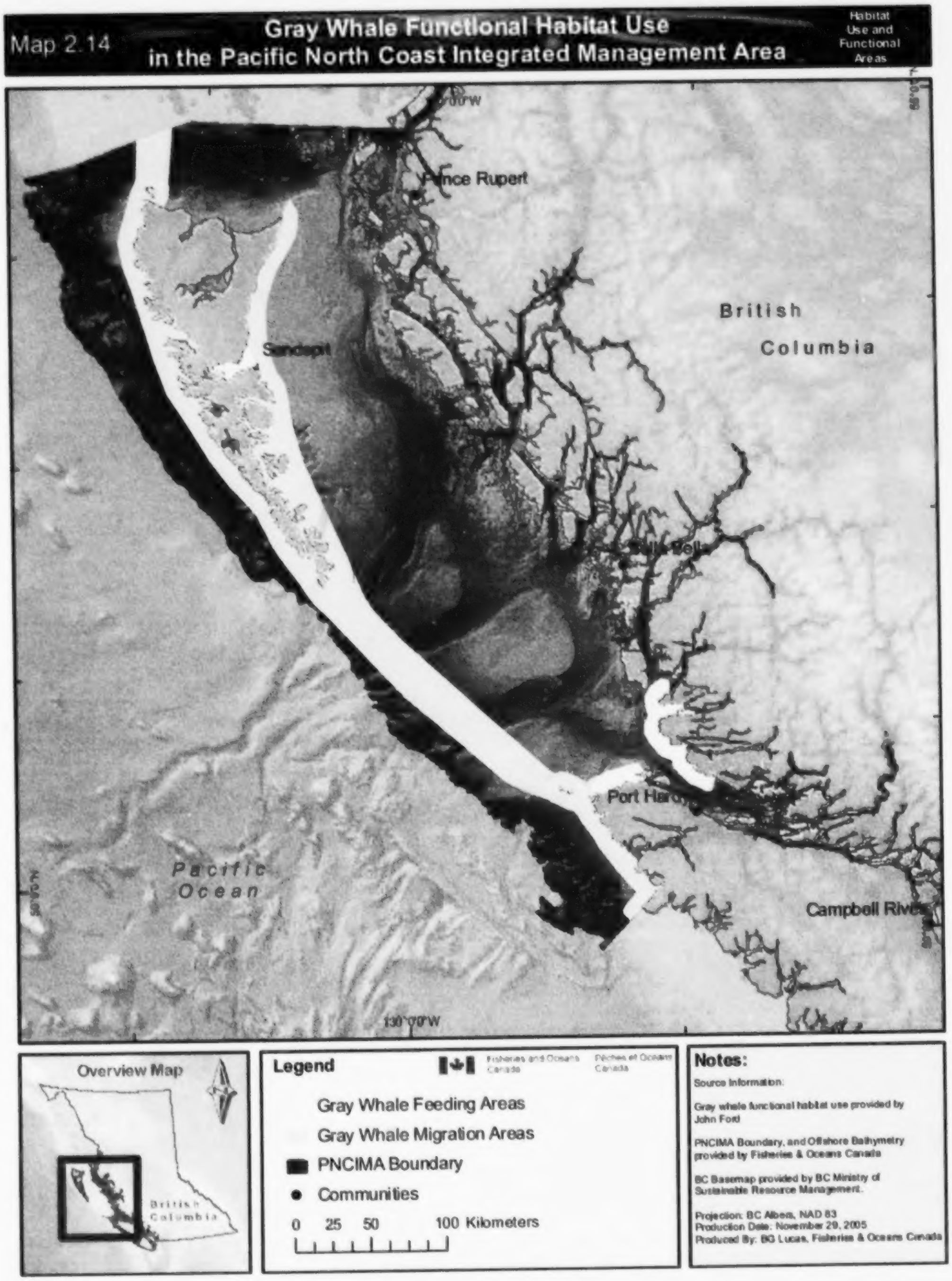
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: June 5, 2007
Produced By: BG Lucas, Lucas Research

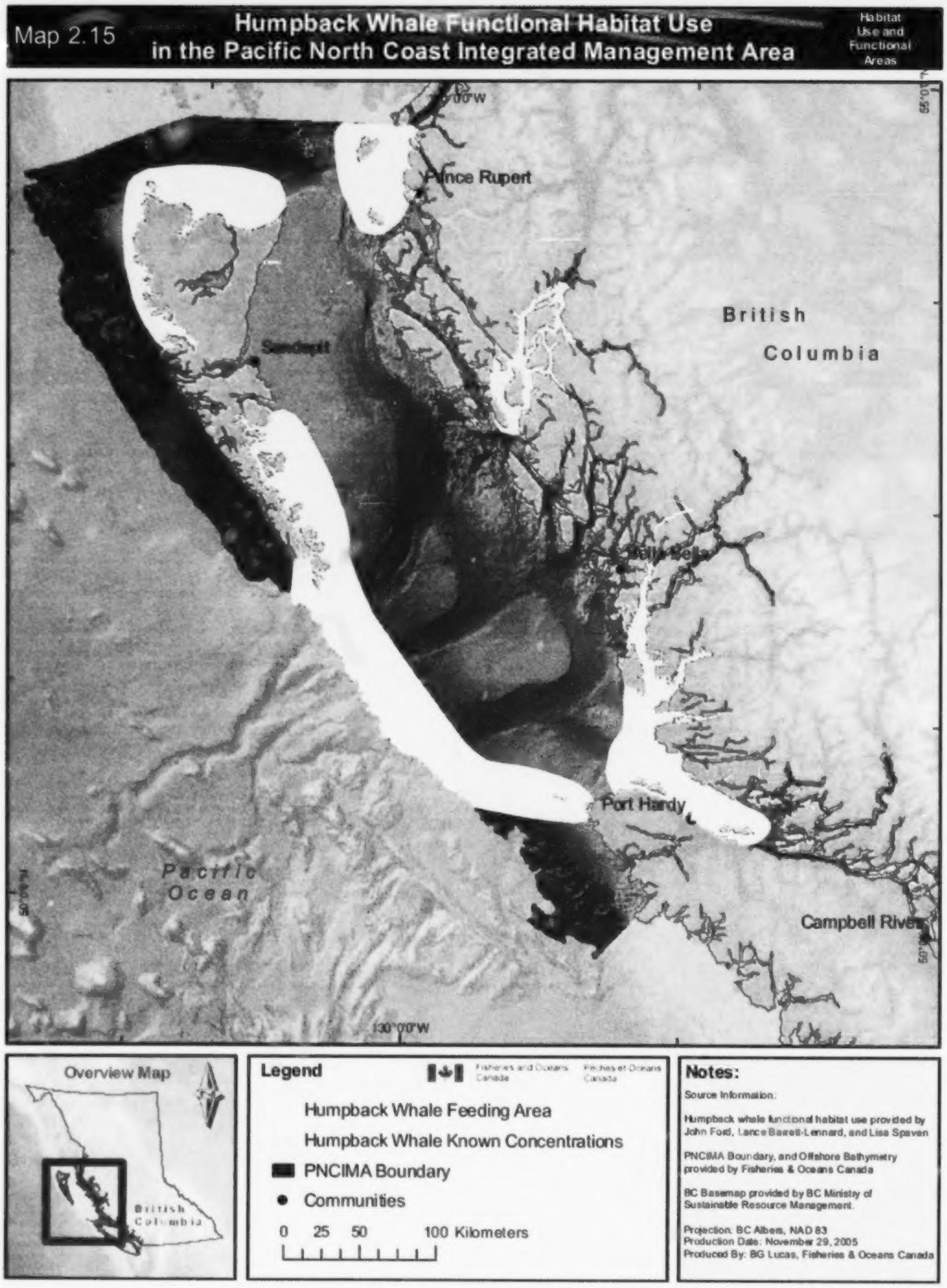
Map 2.12 Herring functional habitat use in PNCIMA.


Map 2.13
Eulachon Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
Prince Rupert
Sandspit
British Columbia
Bella Bella
Port Hardy
Campbell River
Pacific Ocean
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Eulachon Spawning/Rearing Areas
Eulachon Summer Feeding Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Eulachon functional habitat use provided by Doug Hay and Tom Therriault
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: December 5, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

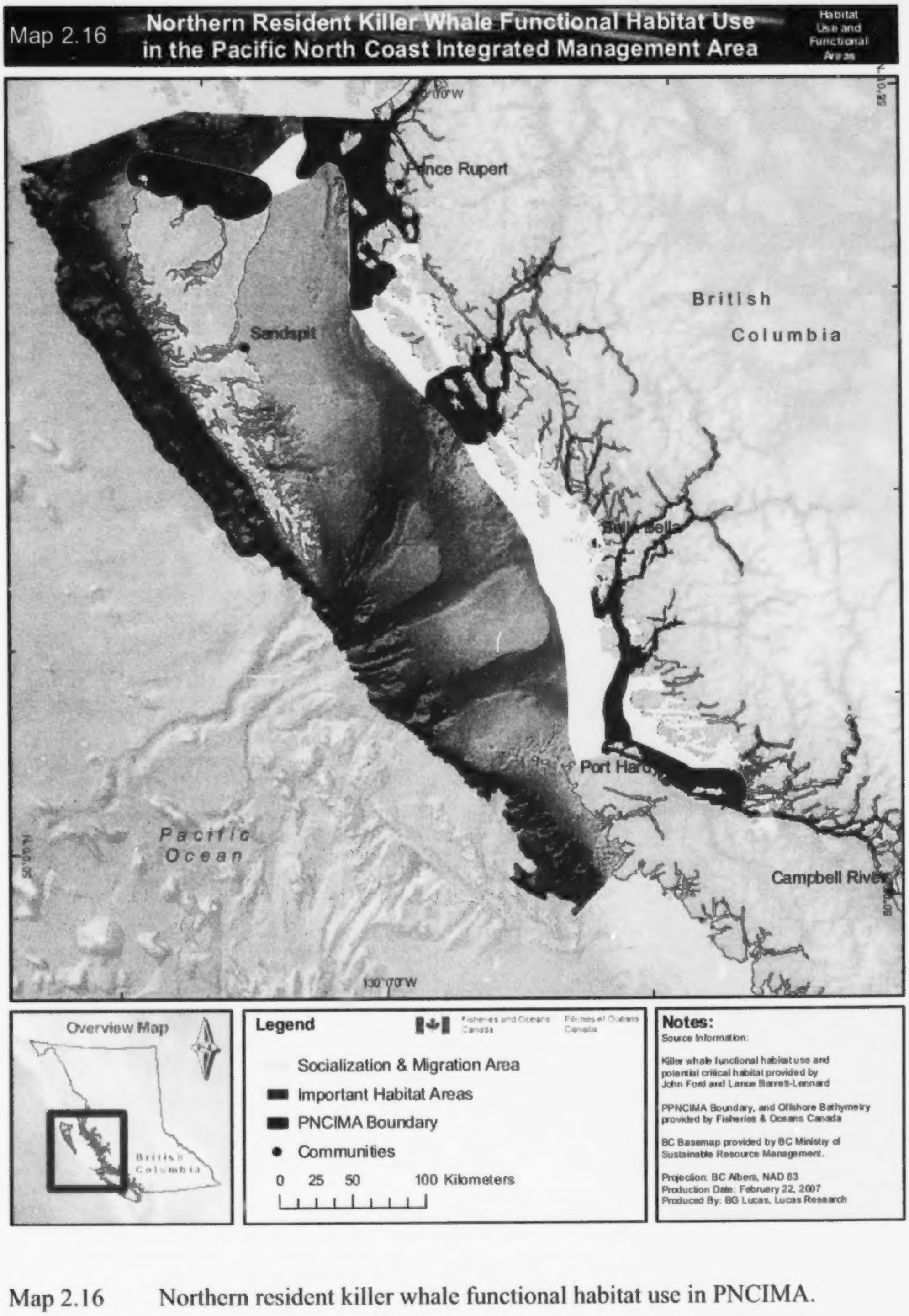
Map 2.13 Eulachon functional habitat use in PNCIMA.


Map 2.14
Gray Whale Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Gray Whale Feeding Areas
Gray Whale Migration Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Gray whale functional habitat use provided by John Ford
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: November 29, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.14 Gray whale functional habitat use in PNCIMA.


Map 2.15
Humpback Whale Functional Habitat Use in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British Columbia
Bella Bella
Port Hardy
Campbell River
Pacific Ocean
130°0'0"W
55°0'0"N
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Humpback Whale Feeding Area
Humpback Whale Known Concentrations
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Humpback whale functional habitat use provided by John Ford, Lance Barrett-Lennard, and Lisa Spaven
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: November 29, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.15 Humpback whale functional habitat use in PNCIMA.


Map 2.16
Northern Resident Killer Whale Functional Habitat Use in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British Columbia
Bella Bella
Port Hardy
Campbell River
Pacific Ocean
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Socialization & Migration Area
Important Habitat Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers

Notes:
Source Information:

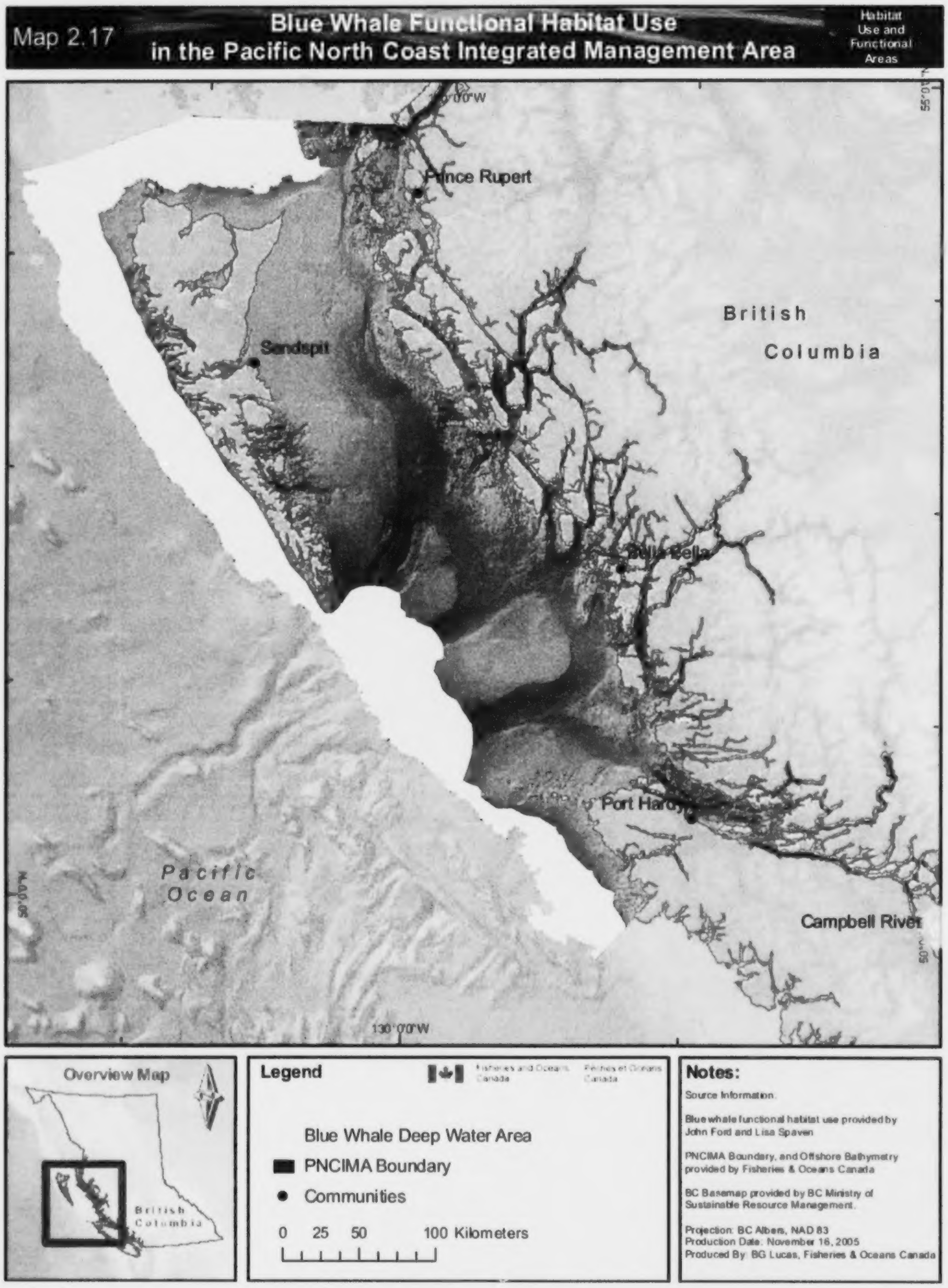
Killer whale functional habitat use and potential critical habitat provided by John Ford and Lance Barrett-Lennard

PPNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.16 Northern resident killer whale functional habitat use in PNCIMA.


Map 2.17
Blue Whale Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
50°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Blue Whale Deep Water Area
▆ PNCIMA Boundary
● Communities
0 25 50 100 Kilometers

Notes:

Source Information:

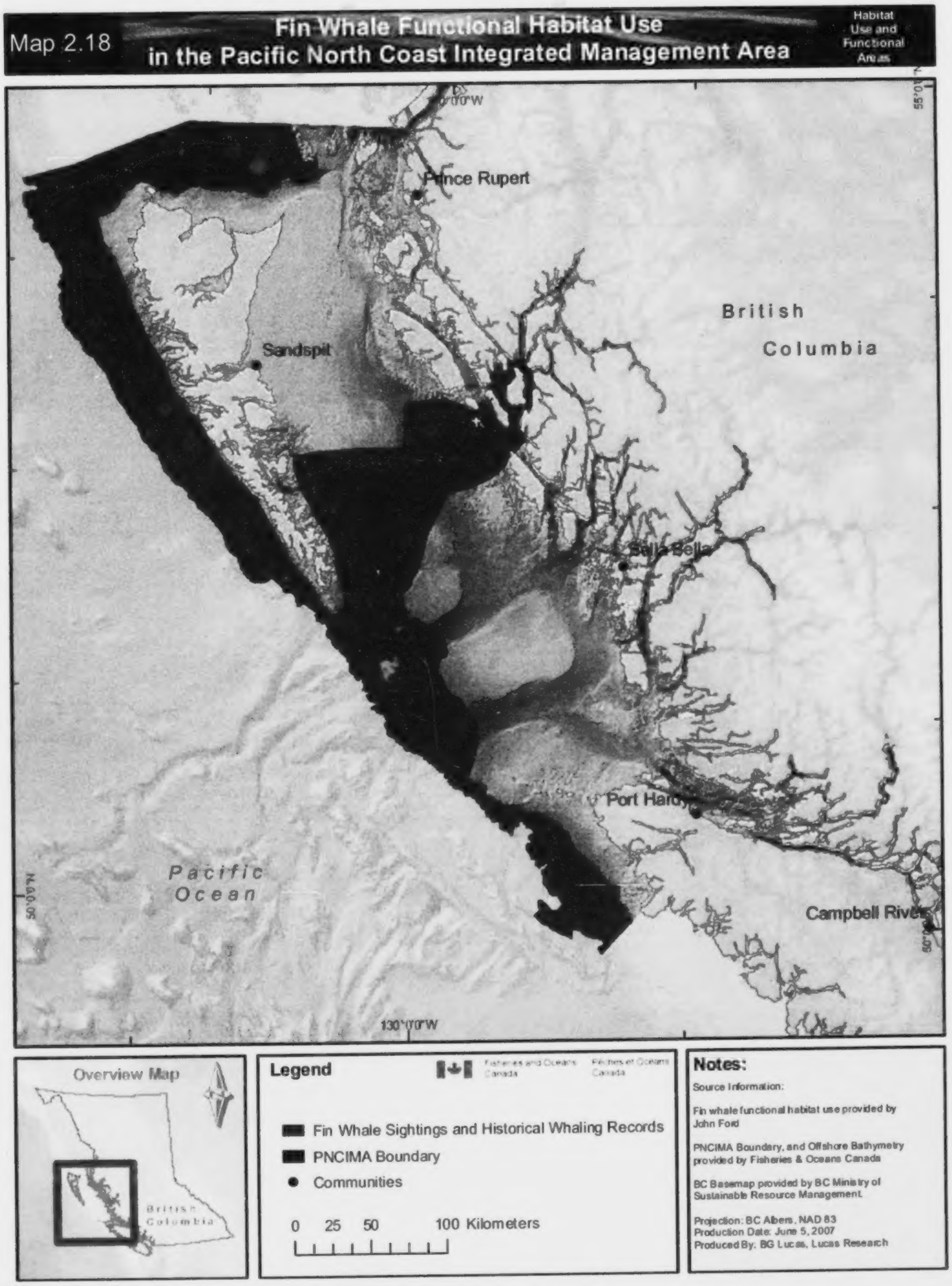
Blue whale functional habitat use provided by John Ford and Lisa Spaven

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 16, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.17 Blue whale functional habitat use in PNCIMA.


Map 2.18
Fin Whale Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Fin Whale Sightings and Historical Whaling Records
PNCIMA Boundary
Communities
0 25 50 100 Kilometers

Notes:

Source Information:

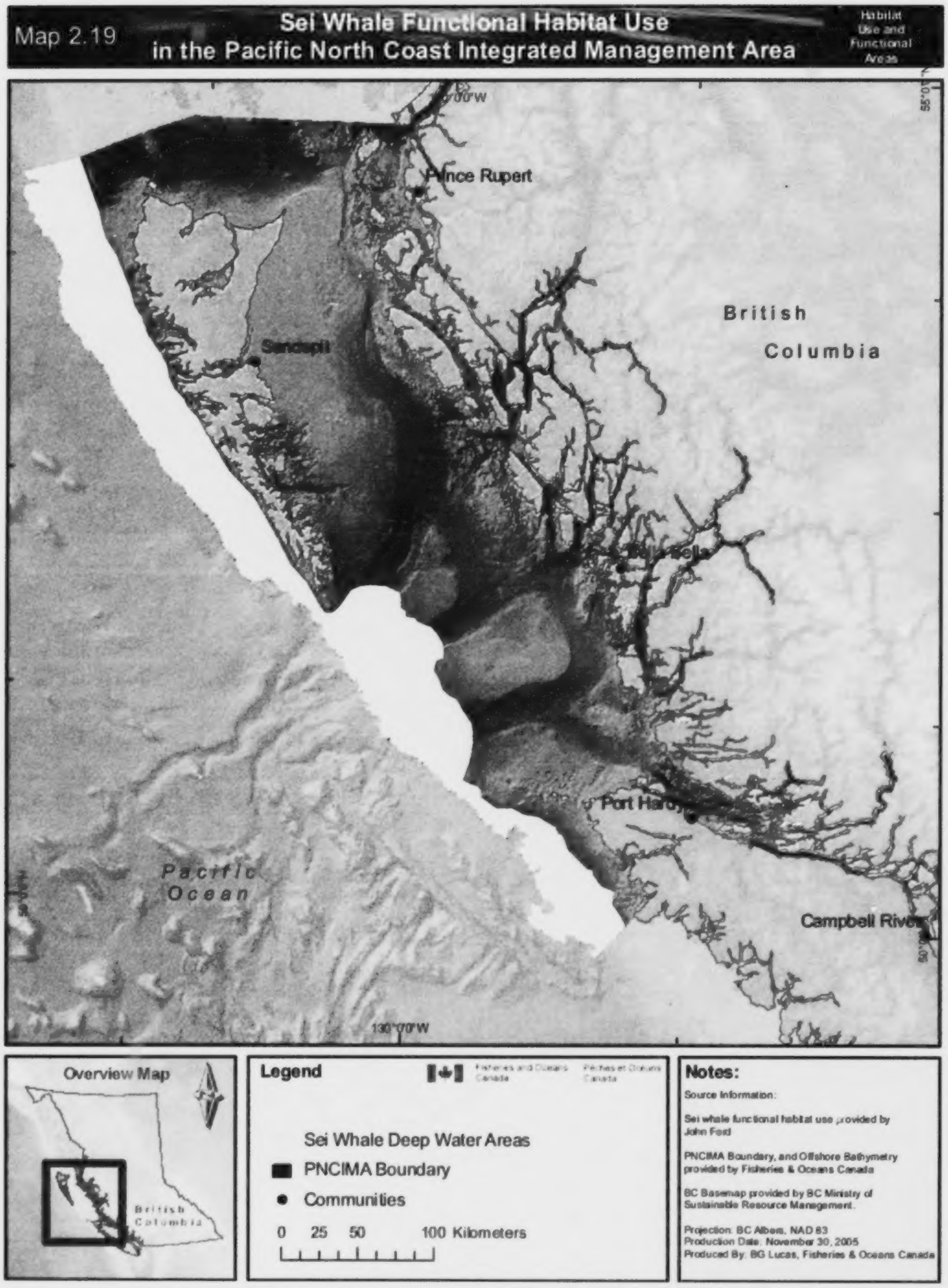
Fin whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

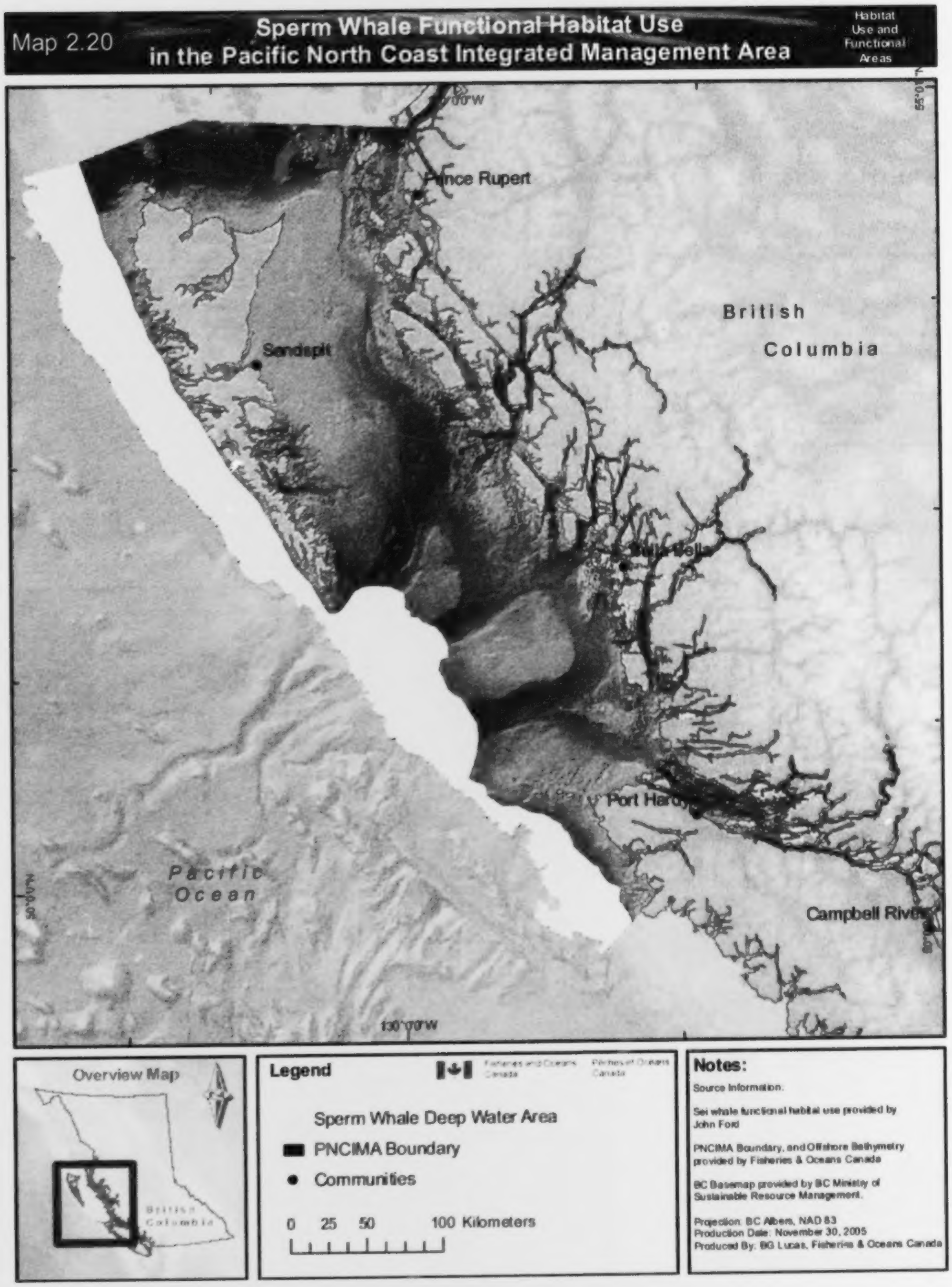
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: June 5, 2007
Produced By: BG Lucas, Lucas Research

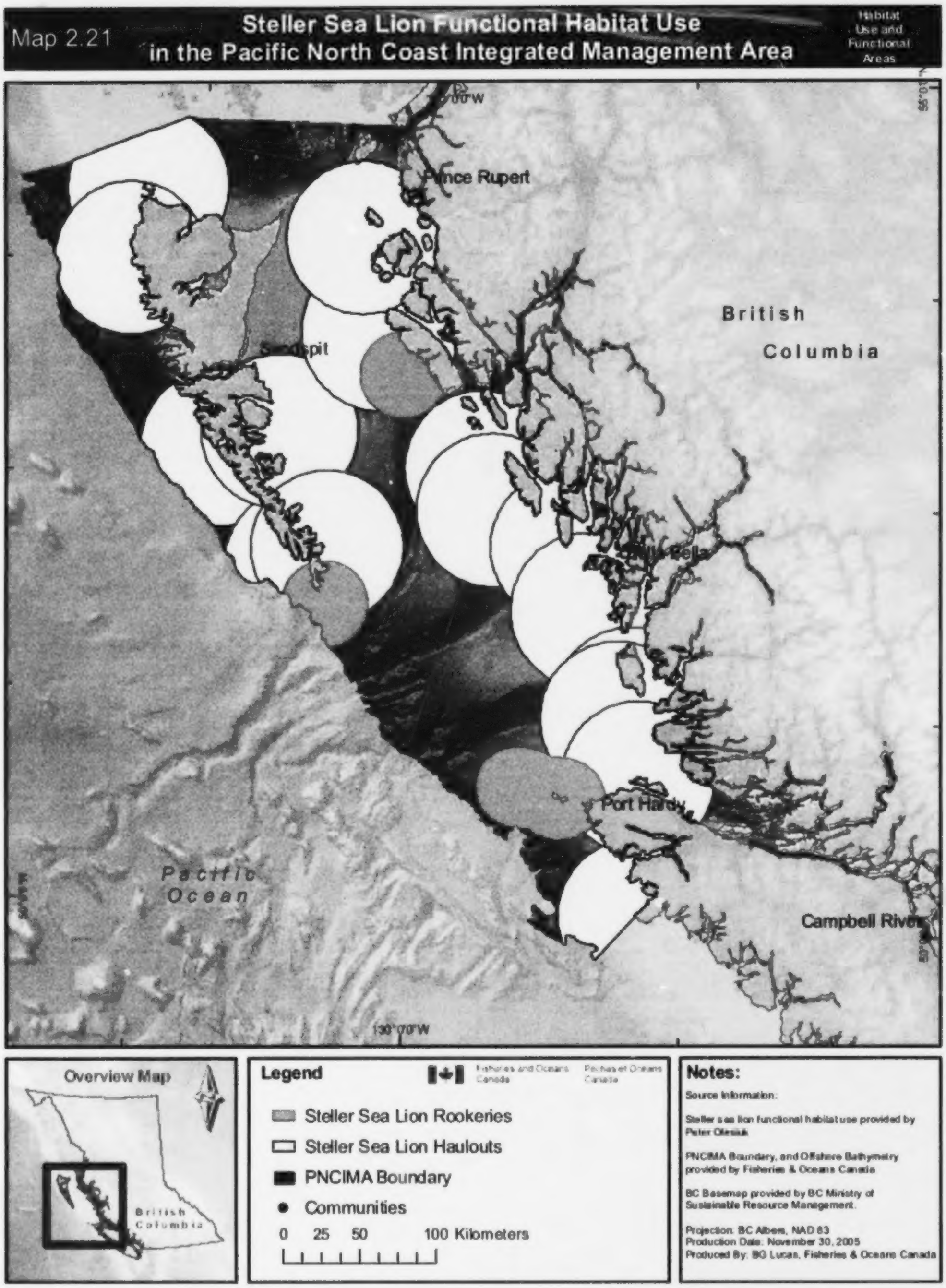
Map 2.18 Fin whale functional habitat use in PNCIMA.


Map 2.19
Sei Whale Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°00'W
55°0'N
Prince Rupert
Sandspit
British Columbia
Bella
Port Hardy
Pacific Ocean
Campbell River
50°0'N
130°00'W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Sei Whale Deep Water Areas
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Sei whale functional habitat use provided by John Ford
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.19 Sei whale functional habitat use in PNCIMA.


Map 2.20
Sperm Whale Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
50°0'0"N
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Sperm Whale Deep Water Area
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Sei whale functional habitat use provided by John Ford
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.20 Sperm whale functional habitat use in PNCIMA.


Map 2.21
Steller Sea Lion Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat
Use and
Functional
Areas
130°0'0"W
55°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Pacific
Ocean
Campbell River
50°0'0"N
130°0'0"W
Overview Map
British
Columbia
Legend
Fisheries and Oceans
Canada
Pêches et Océans
Canada
▨ Steller Sea Lion Rookeries
☐ Steller Sea Lion Haulouts
■ PNCIMA Boundary
● Communities
0
25
50
100 Kilometers
Notes:

Source Information:

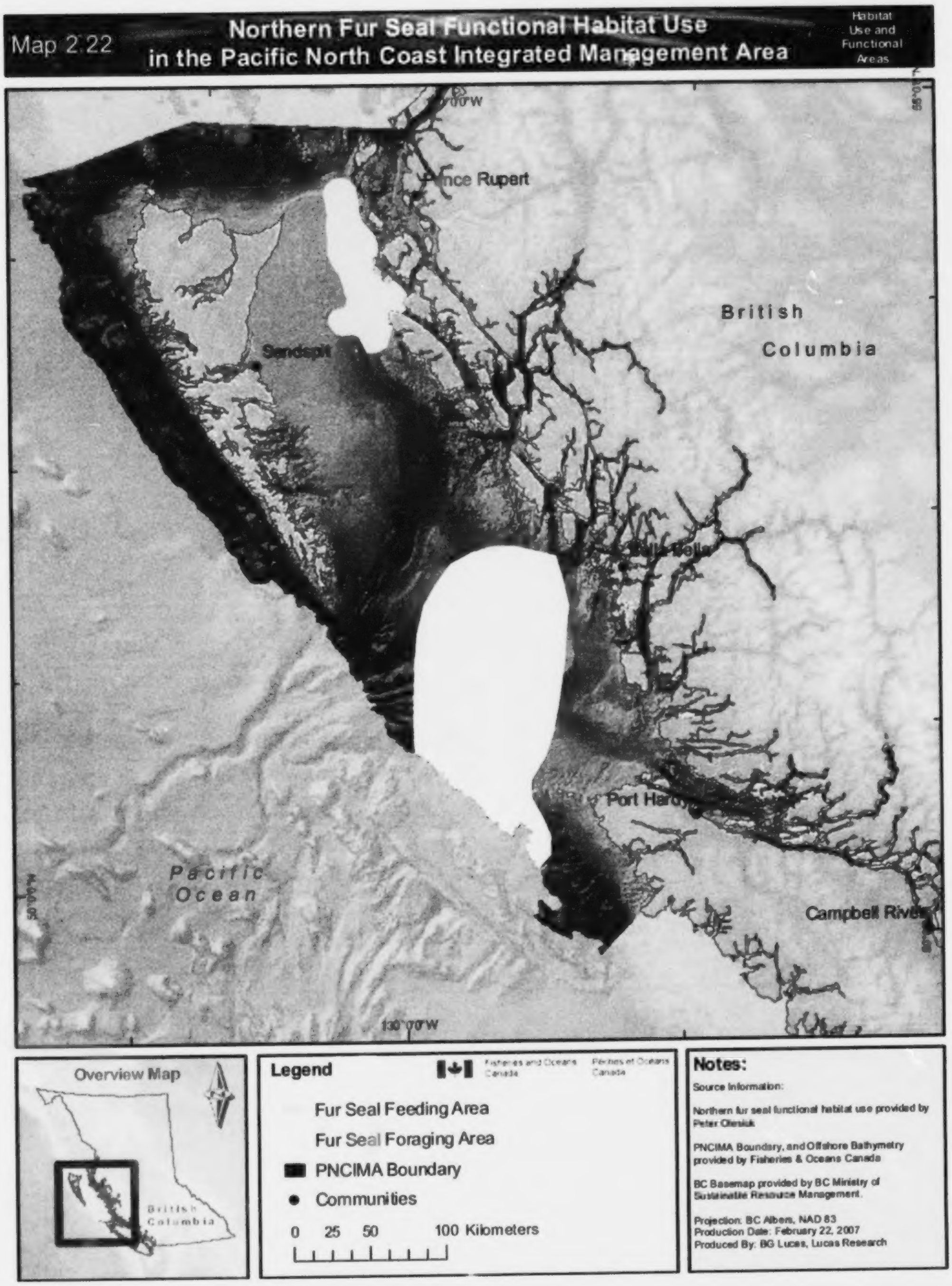
Steller sea lion functional habitat use provided by Peter Olesiuk

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

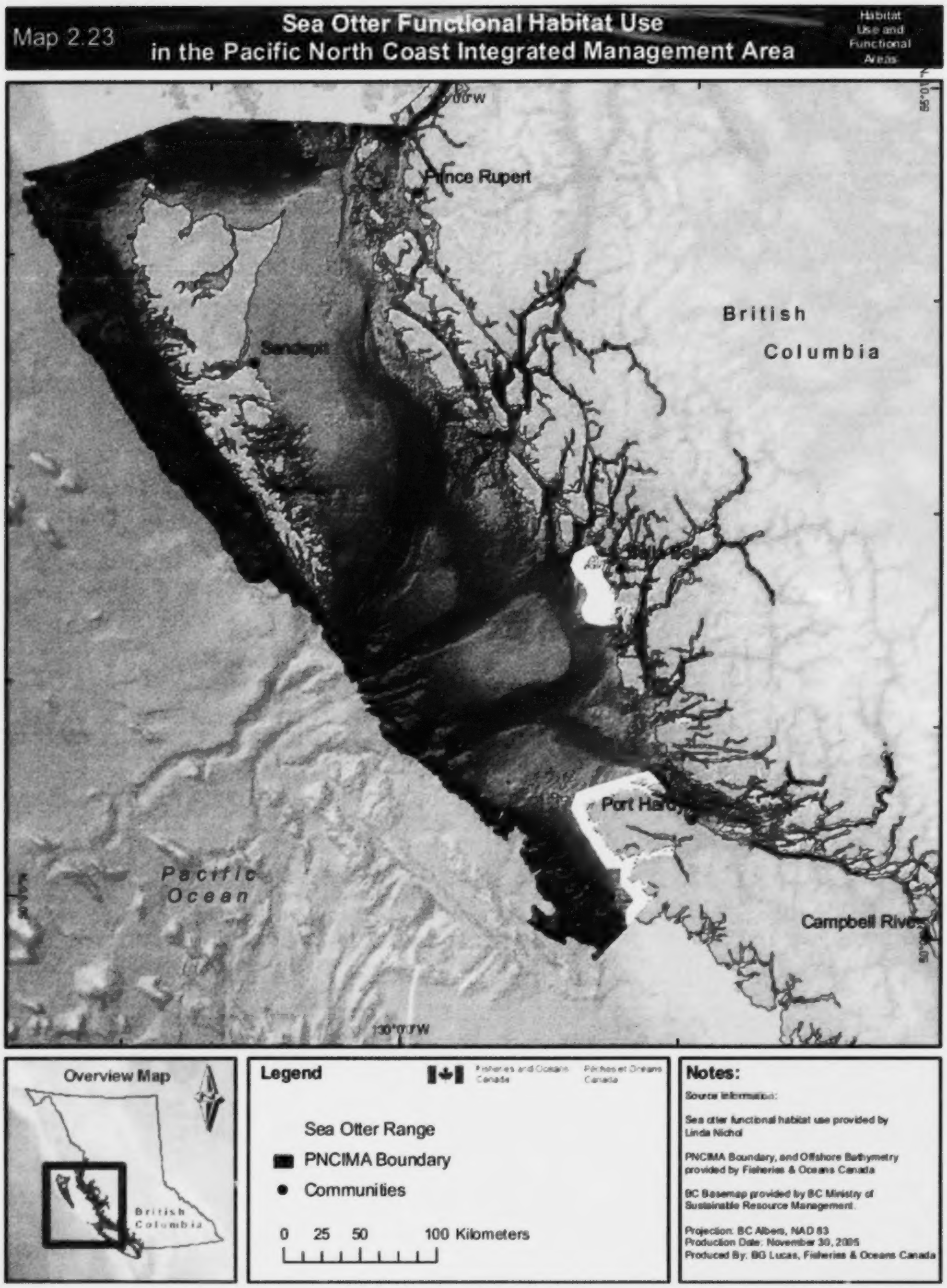
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.21 Steller sea lion functional habitat use in PNCIMA.


Map 2.22
Northern Fur Seal Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
50°0'0"N
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Fur Seal Feeding Area
Fur Seal Foraging Area
PNCIMA Boundary
Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Northern fur seal functional habitat use provided by Peter Olesiuk
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.22 Northern fur seal functional habitat use in PNCIMA.


Map 2.23
Sea Otter Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
Prince Rupert
Sandspit
British Columbia
Port Hardy
Campbell River
Pacific Ocean
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Sea Otter Range
PNCIMA Boundary
● Communities
0 25 50 100 Kilometers
Notes:

Source information:

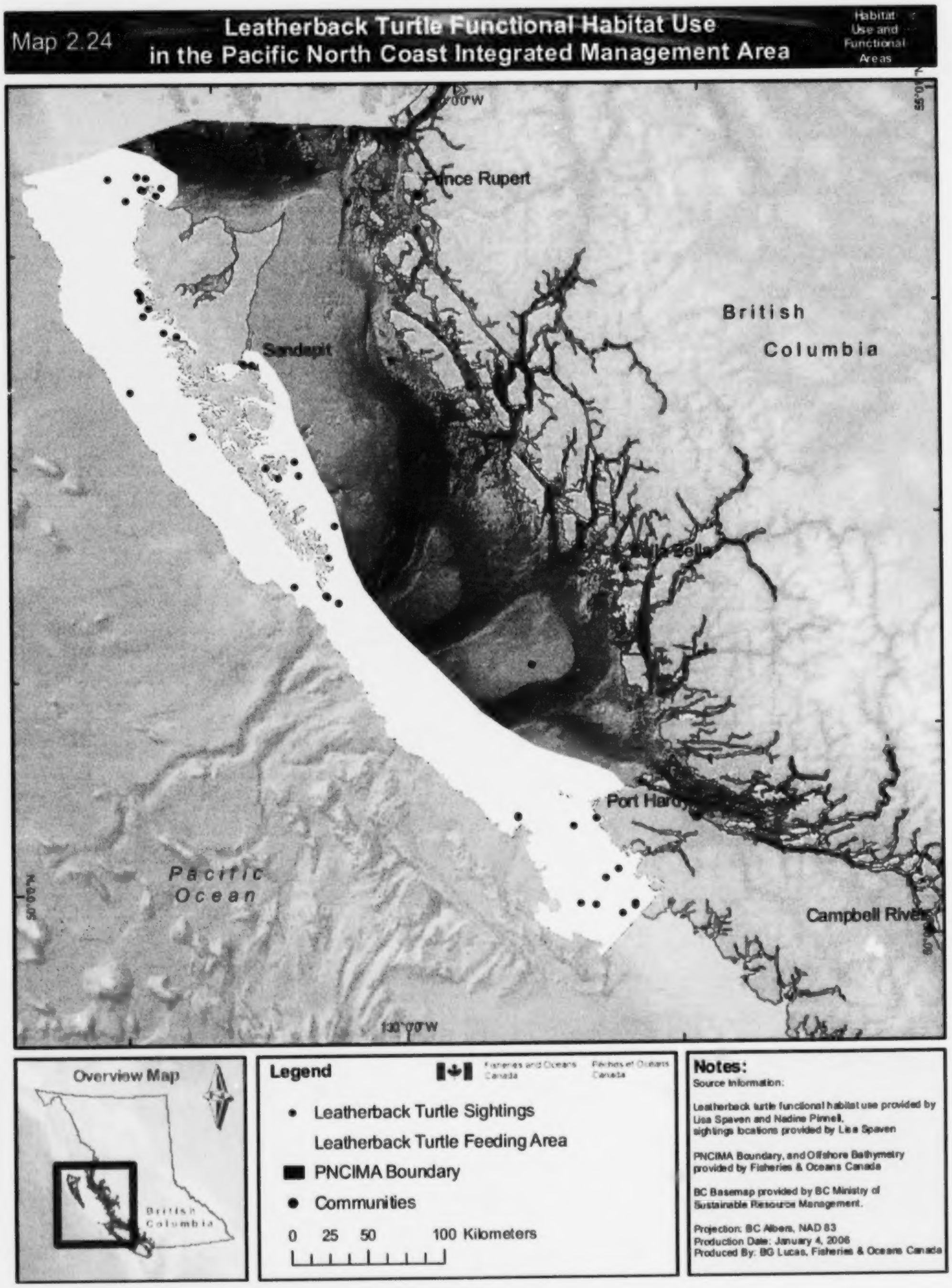
Sea otter functional habitat use provided by Linda Nichol

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.23 Sea otter functional habitat use in PNCIMA.


Map 2.24
Leatherback Turtle Functional Habitat Use
in the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
Prince Rupert
Sandspit
British
Columbia
Bella Bella
Port Hardy
Campbell River
Pacific
Ocean
55°0'0"N
50°0'0"N
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
● Leatherback Turtle Sightings
Leatherback Turtle Feeding Area
PNCIMA Boundary
● Communities
0 25 50 100 Kilometers
Notes:
Source Information:
Leatherback turtle functional habitat use provided by Lisa Spaven and Nadine Pinnell,
sightings locations provided by Lisa Spaven
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management.
Projection: BC Albers, NAD 83
Production Date: January 4, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.24 Leatherback turtle functional habitat use in PNCIMA.

GLOSSARY

Accreted – Accretion is a process in which parts of the Earth's crust are solidified into larger bodies of rock.

Agglomerative clustering – Start by treating each object as a separate cluster, then group them into bigger and bigger clusters.

Anthropogenic – Human-caused.

Benthivores – An animal which feeds on animals that live on the sea floor.

Convergent – Processes by which water and particles in the water are aggregated.

Coriolis force – An apparent force exerted on moving parcels of water due to the rotation of the Earth; e.g. net movement of water is to the right of the wind direction in the Northern Hemisphere.

Demersal – On or associated with the sea floor.

Dendrogram – A tree-form diagram that is a graphic depiction of hierarchical relationships between sequences or organisms.

Detritus – Dead particulate organic material.

Diel – A daily cycle. Diel variation usually occurs once for every 24 hr period.

Downwelling – Sinking of higher density water, uaully driven by surface winds from a particular direction.

Ekman downwelling – Downwelling of surface water driven by the wind.

Epifauna – Animals that live on the surface of the sea floor.

Fecund – Species that have a high reproductive output based on when and how often they reproduce.

Fluvial – Related to flowing water; fluvial erosion refers to erosion by moving water, such as rivers.

Gametogensis – The formation of male and female gametes (egg and sperm) by meiosis.

Gonad – Reproductive organ.

Ichthyoplankton – Finfish and invertebrates which live by floating in the water; usually refers to the larval stages of finfish and invertebrates which can move against ocean currents as adults.

Inexorable – Relentless, inevitable.

Littoral – The coastal, near-shore, areas of an ocean or sea.

Macrophyte –Large aquatic plants.

Megalopa – Late larval stage.

Metamorphosis – Change in form during development.

Monotonic increase – Consistently increasing.

Moulting – To shed outer shell or exoskeleton.

Non-intermittent spawners – Individuals release all their eggs at one time.

Ontogenetic variability (in diet) – Variability relatied to the origin and development of individual organisms.

Piscivore – An animal which feeds on fish.

Planktivore – An animal which feeds primarily on plankton; plankton is the collective group of tiny plants and animals that float or drift near the surface of a body of water; plankton is very low on the aquatic food chain and therefore a vital element in that ecosystem.

Planktonic – Drifting small organisms that inhabit the water column of the ocean.

Sexual dimorphism – A distinct difference in appearance between males and females of the same species.

Terranes – A section of the earth's crust that has collided with and and become attached to a different part of the Earth's crust, as in a continental margin.

Upwelling winds – Winds that drive upwelling of denser and cooler water towards the ocean surface.

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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX A: GEOLOGY

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1.0 INTRODUCTION

The Pacific Coast as it is seen today is the result of geological processes that have been ongoing for hundreds of millions of years. Over the largest time scale, the dominant process involved is plate tectonics, by which terranes from other parts of the world were accreted onto North America. Much of British Columbia (BC) was added on to North America in this way. The slow but inexorable forces involved in this process also caused the complex tectonic uplift, faulting and buckling of the crust resulting in the formation of the margin parallel mountain ranges of BC. Subsequent erosion of these mountains infilled the sedimentary basins that developed through faulting and subsidence between these ranges.

The tectonic forces that have formed the western Canadian margin continue to this day and BC's offshore is underlain by a complex combination of plate boundaries including a subduction zone, spreading ridges, and transform faults. This results in a variety of earthquake environments frequently generating earthquakes of magnitudes greater than 9 that have occurred roughly once every 300 to 500 years.

Over the last two million years, glaciation has been a dominant factor in the development of BC landscapes, surficial geology and soils. In many areas, subsequent glaciations have largely erased the effects of the previous ones, and as a result, many of the glacial features seen today are a product of the last glacial advance (between 10 and 30 thousand years ago). The terrestrial glacial surface has, in turn, been modified by fluvial erosion and deposition during postglacial time (the last 10,000 years), while marine geomorphology has been shaped by changing sealevels, tides, currents, and littoral processes. Continentally derived sediment input to the continental shelf has been limited since glacial retreat because the deep basins of the coastal fjords and channels allow the settling of river borne sediments. This results in a 'sediment starved' shelf where the older glacial deposits are re-worked in shallow water less than 100 m. This condition has also meant that a relict shelf occurs in deeper water where conditions have remained relatively unchanged, and a coastline dominated by rocky shores with few sand and gravel beaches.

The physical features of the coast also affect the freshwater input to the marine area. PNCIMA contains a variety of watershed forms resulting in different hydrologic profiles, though spring and summer meltwater runoff dominate the mainland watersheds which provide most of the freshwater input. This input and its timing are critical to phytoplankton blooms which form the base of the marine food chain. Global warming is already seen to be affecting the timing and volume of freshwater input in this area.

PNCIMA also has a potential to host significant petroleum resources. The Queen Charlotte Basin is one of four sedimentary basins found on Canada's Pacific margin. Explorations from the 1960s to the 1980s suggest that this basin may hold significant reserves of oil and gas. Natural gas hydrates have also been found on southern portions of BC's continental slope and may also exist on the slope within PNCIMA.

1.1 Key Points

The geological environment forms the underlying habitat of the area and significantly affects the physical functioning of the ecosystem. This includes such features as:

- the steep and rugged coastal mountains and their effect on climate, rainfall and watershed function,
- the valleys and fjords that cut into these mountains resulting in the dominance of estuarine circulation in the nearshore environment and creating a sediment-starved shelf,
- the abundant mainland islands creating many kilometres of protected and semi-protected coastline and waterways,
- the presence of the Queen Charlotte and Vancouver islands (Figure A.0) which give rise to a wide range of wave exposure regimes and affect currents and oceanographic circulation in the area,
- the glacially scoured continental shelf with its cross cutting troughs, intervening banks and the dominance of glacially derived sediments which are likely to be a controlling factor in benthic habitats,
- the presence of the Queen Charlotte Basin beneath the continental shelf, which has the potential to contain significant oil and gas reserves, and the presence of onshore oil seeps and offshore pockmarks and shallow gas fields that are manifestations of hydrocarbons leaking from and through the basin rocks,
- the seismic activity of the area which is prone to a wide range of magnitudes of earthquakes,
- the recently discovered siliceous sponge reefs are globally rare and are suspected of being a critical habitat for a variety of species including rockfish and juvenile fish of various species,
- the coastal sedimentary regime in the shallow western portion of Hecate Strait that has led to rapid coastal retreat along the eastern Graham Island shore and growth of Rose Spit and the northern side of Graham Island.

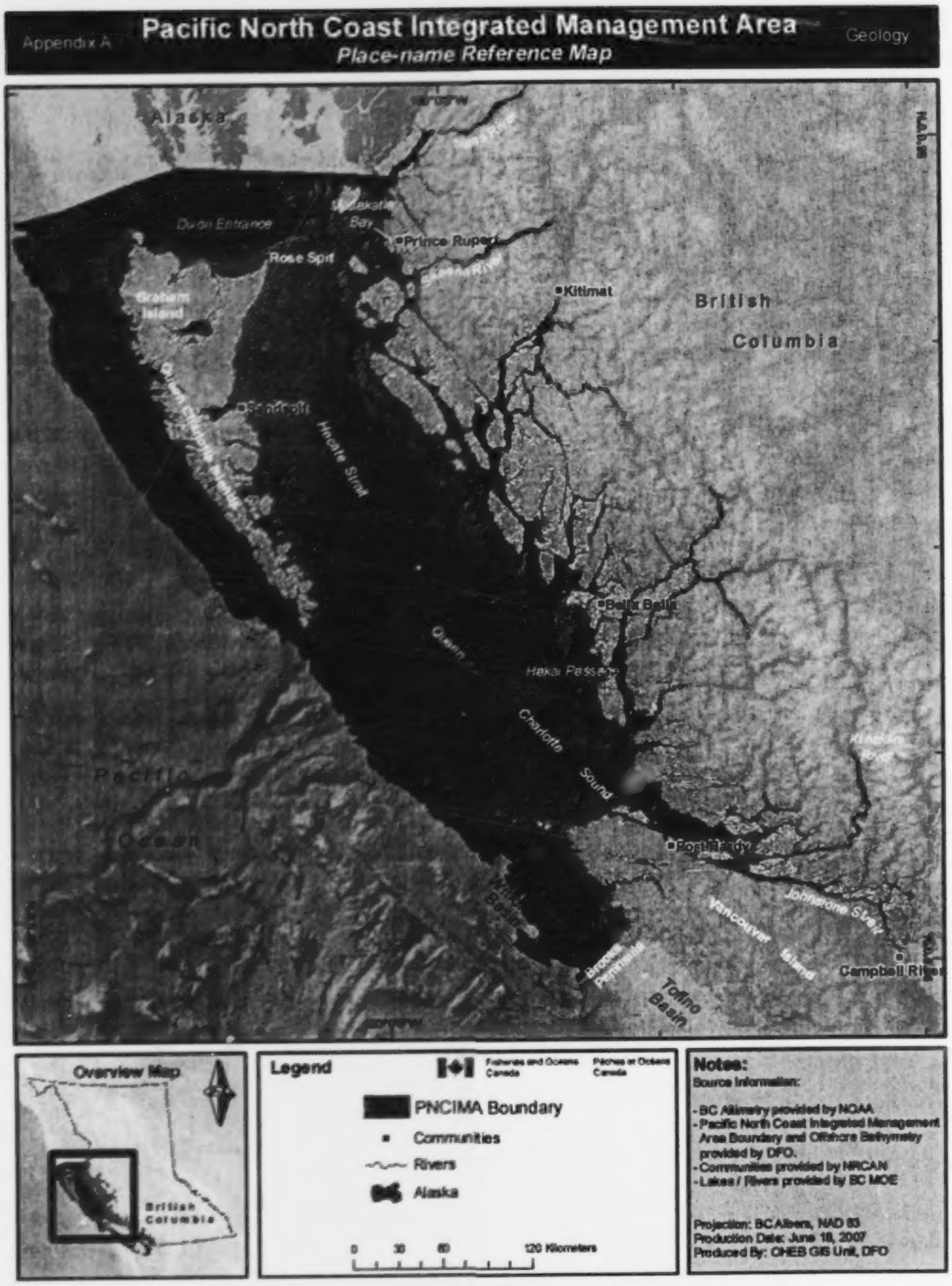

Appendix A
Pacific North Coast Integrated Management Area
Place-name Reference Map
Geology
Alaska
Dixon Entrance
Bay
Prince Rupert
Rose Spit
Skeena River
Kitimat
British
Columbia
Graham
Island
Sandspit
Hecate Strait
Bella Bella
Queen
Hakai Passage
Charlotte
Sound
Pacific
Ocean
Port Hardy
Basin
Brooks
Peninsula
Tofino
Basin
Vancouver
Island
Johnstone Strait
Campbell River
Overview Map
British
Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Rivers
Alaska
0
30
60
120 Kilometers
Notes:
Source Information:
-BC Altimetry provided by NOAA
-Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
-Communities provided by NRCAN
-Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure A.0 PNCIMA region showing locations and features of BC waters.

1.2 Uncertainties, Limitations, and Variability

Terrestrial bedrock geology is well understood in PNCIMA. Submarine bedrock geology is less well constrained. Current knowledge of seafloor sediments and substrate material is patchy and in most areas limited by the need to extrapolate between widely spaced sampling points and geophysical survey lines. The surficial geology is likely to be a significant factor in determining benthic habitat conditions. Understanding of the role of surficial materials as habitat and how they interact with various biota is critical to understanding benthic ecosystem function.

Multibeam sonar technology is providing high-resolution bathymetric and seabed characterization data, though it will require many years to compile a shelf-wide dataset. Detailed understanding of marine geohazards within the region is limited. Slope stability could represent a significant geohazard as extensive areas of slumped and failed sediments have been described in the PNCIMA region, but much further work is required to provide constraints to the degree of risk associated with this potential hazard. Knowledge of the erosion, transport, and deposition of marine sediments within PNCIMA is generally poor and extensive new research would be required to advance understanding in this area. While the exact timing of large earthquakes cannot be predicted, current understanding allows a high degree of certainty that the subduction zone off of the west coast of Vancouver Island is currently locked and will likely produce an earthquake around magnitude 9 within the next several hundred years. The transform fault off the Queen Charlotte Islands is known to produce greater than magnitude 8 earthquakes, and is the site of Canada's largest recorded earthquake, a magnitude 8.1 event in 1949, but the frequency of these events is unknown. Oil and gas seeps have been encountered onshore and more recently offshore. Study of these submarine gas vent sites has only begun. In view of the moratoria on oil and gas exploration, field research regarding the petroleum resources of the region has languished, with the last multichannel seismic survey undertaken to assess structural controls on basin development being done nearly 20 years ago.

1.3 Major Sources of Information or Data

Geoscience research including onshore and marine mapping, maintenance of GIS databases, and regional survey work is done by the Geological Survey and Development Branch of the provincial Ministry of Energy and Mines and the Pacific division of the Geological Survey of Canada (GSC), a part of the Earth Sciences Sector of Natural Resources Canada. The Pacific Geoscience Centre (GSC office in Sidney) is the base of the marine geology and earthquake seismology expertise in this region.

1.3.1 Multibeam Surveys

The Canadian Hydrographic Service of Fisheries and Oceans Canada (DFO) in association with the GSC are undertaking extensive and detailed multibeam sonar surveys of the continental shelf and upper slope. The vessels employed in this program include the *CCGS Vector* and the motor launch *Otter Bay*. The vessels are utilized in different depth ranges for the multibeam survey work as a consequence of the type of equipment mounted, with *Otter Bay* normally surveying from 5 – 150 m water depth while the *Vector* typically surveys deeper than 80 m and resolution is limited to waters less than 800 m depth. The deeper portion of PNCIMA will thus require a different vessel or multibeam system for deep-water surveys on much of the slope. Apart from the bathymetric data, backscatter or seabed reflectivity data are collected simultaneously that provides information about the character and potentially the texture of the seabed. In addition, recent research is being devoted to analyzing the properties of the water column reflections that occur in a swathed area with the objective of describing biotic or oceanographic phenomena in the water column. This ongoing work will provide highly detailed digital datasets and maps of seafloor topography and the backscatter data will facilitate the mapping of the surficial geology including seafloor sediment texture.

Useful publications summarizing geologic information for this area include:

- Two major summary books for the area are:
    - Geology of the Cordilleran Orogen in Canada (Gabrielse and Yorath *eds*. 1991); and
    - Quaternary Geology of Canada and Greenland (Fulton *eds*. 1989).
- Two excellent books for the general public are:
    - Geology of British Columbia: A Journey Through Time (Cannings and Cannings 1999); and
    - Where Terranes Collide (Yorath 1990).
- Numerous reports on Offshore Oil and Gas have been produced and generally provide excellent summaries of a number of topics including the geology of the area. These reports include:
    - Offshore Queen Charlotte Islands Initial Environmental Evaluation Volumes 1-3 (Petro-Canada 1983);
    - Initial Environmental Evaluation for Renewed Petroleum Exploration in Hecate Strait and Queen Charlotte Sound Volumes 1 & 2 (Chevron Canada Resources Ltd. 1982);
    - British Columbia Offshore Oil and Gas Technology Update (Jacques Whitford Environment Limited 2001);
    - British Columbia Offshore Hydrocarbon Development: Report of the Scientific Review Panel (Strong *et al.* 2002);

  - Physical Oceanographic and Geological Setting of a Possible Offshore Oil and Gas Industry in the Queen Charlotte Basin (Cretney *et al.* 2002a);
  - A Review of the State of Knowledge of Marine and Shoreline Areas in the Queen Charlotte Basin (LGL Limited 2004);
  - Report of the Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia (Hall *et al.* 2004).
- Other books and reports containing geological information include:
  - The Outer Shores (Scudder and Gessler *eds*. 1989);
  - The Gulf of Alaska: Physical Environment and Biological Resources (Hood and Zimmerman *eds*. 1986);
  - Biophysical Evaluation of the Central Coast of BC with Special Reference to Aquaculture (Ricker and McDonald 1995);
  - Biophysical Suitability of the North Coast and Queen Charlotte Islands Regions of BC for Salmonid Farming in Net Cages (Ricker and McDonald 1992).

1.4 Data Gaps and Lack of Knowledge

Specific recommendations of the expert panel on science issues to the Royal Society of Canada included swath multibeam mapping (Hall *et al.* 2004), and this gap is being addressed. Multibeam imagery will eventually provide a very detailed base for the complete understanding of the regional seabed surficial geology and seafloor physical environment. The continental shelf will require many (estimated >8) years of surveying at the present rate of data acquisition and the inshore areas of the PNCIMA region will require many additional years of surveying as shallow water ways, channels and shoals are completed. The deeper portion of PNCIMA will require different multibeam technology to be applied to acquire data in water depths greater than 800 m. Other data related to shelf sediments and sedimentology gathered in the inner shelf area of PNCIMA is sparse. Very few studies of the inner shelf seabed geology, inshore geo-environmental processes and the linkages between the open shelf and nearshore areas have been done. Very few geoscience data sets of any type exist for the continental slope of PNCIMA. This portion of PNCIMA represents a significant challenge to survey capacity, given the lack of a suitable multibeam system. Thus the central portion of PNCIMA is well studied in comparison to either the inshore eastern or deep-water western part of the study area.

2.0 BEDROCK GEOLOGY

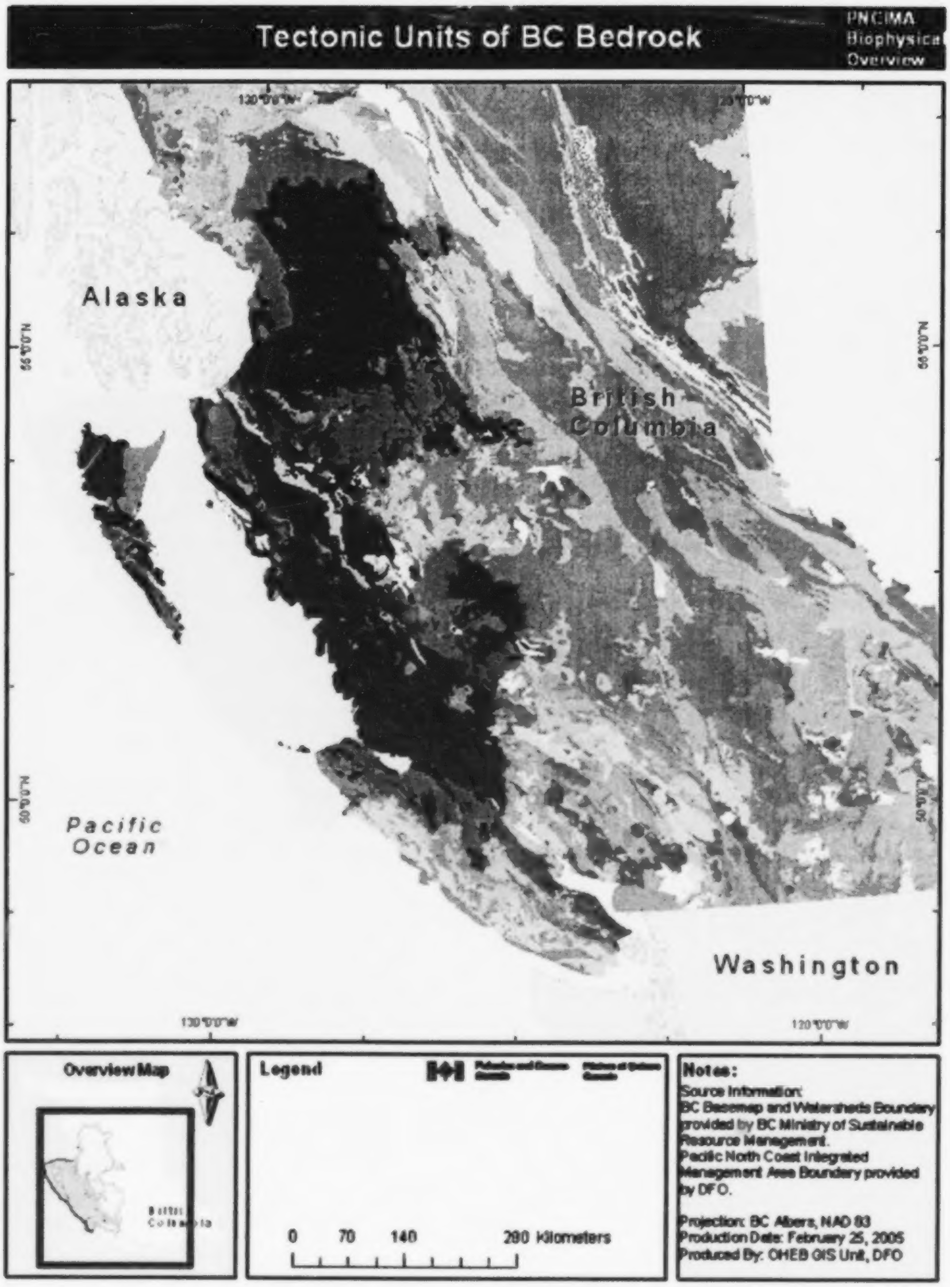
2.1 Makeup and Origin of BC Coastal Bedrock

A detailed summary of British Columbia bedrock geology and tectonic history can be found in Gabrielse and Yorath (1991), particularly Chapter 2 Gabrielse *et al.* (1991) as well as Clague (1989). The following is a summary of the material relevant to this overview.

The level of detail of our current knowledge of BC geology is revealed in the complexity of Figure A.1. This map and Figure A.2 (the same data grouped into simple rock types), reveal a longitudinal northwest trending pattern to the geological makeup of BC. This pattern has been divided into 5 longitudinal belts based on lithology, structural style and morphology (Sutherland Brown *et al.* 1970; Wheeler and Gabrielse 1972 as cited in Gabrielse *et al.* 1991). An increasing understanding of plate tectonic implications of the regional geology of BC was contributed by Monger *et al.* (1972 as cited in Gabrielse *et al.* 1991). In particular it became clear that the physiography and bedrock geology of BC is a result of large-scale tectonic events that have given rise to these distinct longitudinal belts.

In the early 1980s the mapped lithostratigraphic units were categorized according to the setting in which they formed (Tipper *et al.* 1981), resulting in the detailed tectonic assemblage map of Figure A.1. At the same time, information became available that suggested large portions of BC bedrock did not form next to the bedrock they are now found in contact with (Coney *et al.* 1980). This led to the concept of "terranes", which are large pieces of the Earth's crust that have been moved by plate tectonics to their current position. These plates are believed to have broken up and been smashed together many times over the geological history of the Earth. Much of BC is formed from terranes that have been accreted to (piled and smeared up against) the North American continent (Figure A.3). This process has produced that longitudinal appearance of the geological units. The main terranes making up PNCIMA are the Alexander and Wrangellia Terranes, which are believed to have joined together prior to joining on to BC (forming the Insular Superterrane).

The coastal portion of PNCIMA includes the Insular Belt (Vancouver and Queen Charlotte islands and much of the continental shelf) and the Coast Belt which is made up of the mainland's rugged coastal mountain belt. Also, portions of the Intermontane Belt fall within the easternmost edges of the mainland watersheds (Figure A.2). Below is a description of the basic geology of four belts from east to west (summarized from Clague 1989; Gabrielse *et al.* 1991 and http://gsc.nrcan.gc.ca/cordgeo/index_e.php). To illustrate the geologic times listed in the discussion below, refer to Table A.0.


Tectonic Units of BC Bedrock
PNCIMA
Biophysical
Overview
130°0'0"W
120°0'0"W
55°0'0"N
50°0'0"N
Alaska
British
Columbia
Pacific
Ocean
Washington
Overview Map
British
Columbia
Legend
0 70 140 280 Kilometers

Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.

Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.1 Tectonic assemblage map compiled to be accurate at a scale of 1:250 000 (data from the BC Ministry of Energy and Mines 2005).

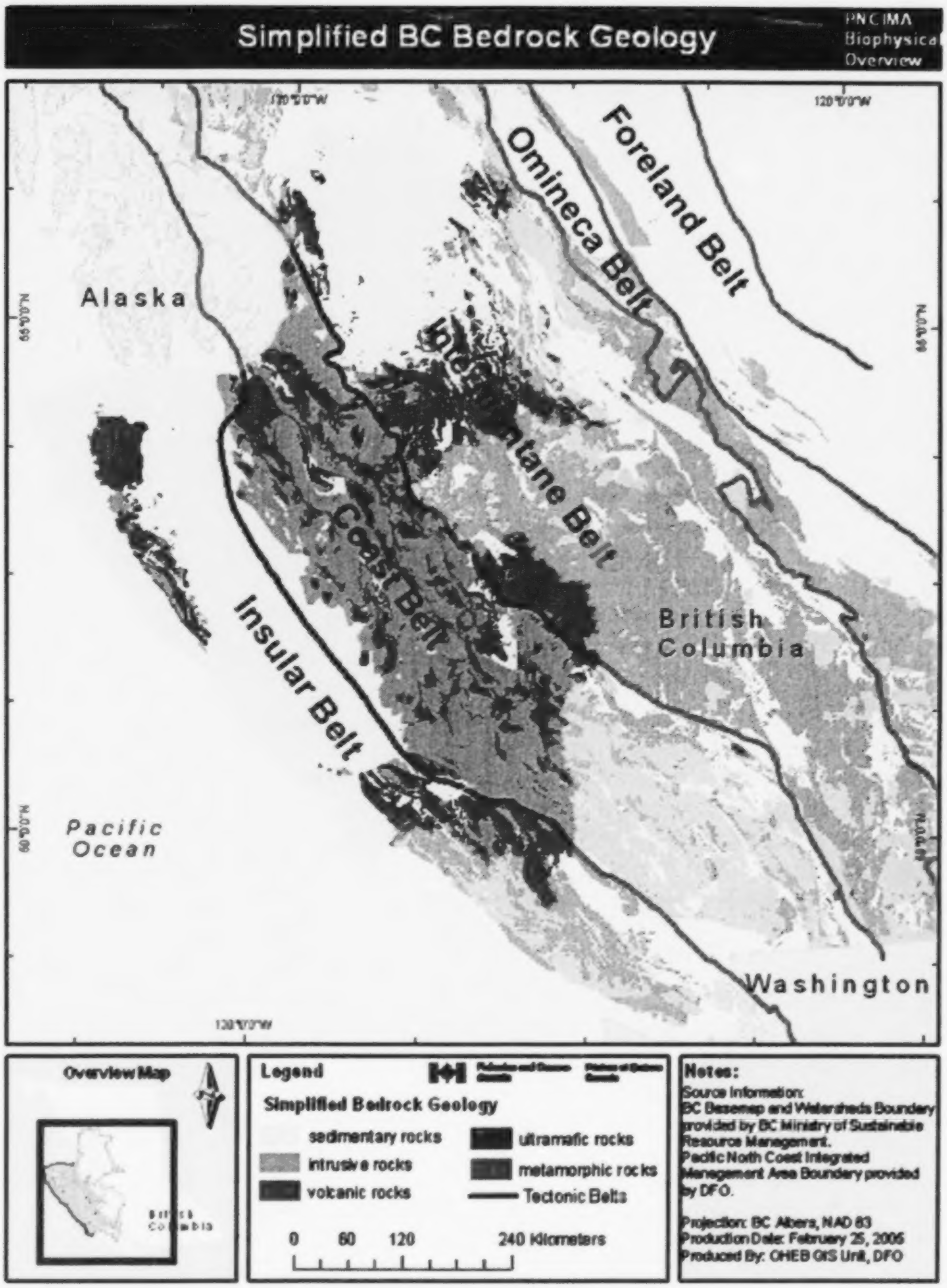

Simplified BC Bedrock Geology
PNCIMA
Biophysical
Overview
130°0'0"W
120°0'0"W
55°0'0"N
50°0'0"N
Alaska
Foreland Belt
Omineca Belt
Intermontane Belt
Coast Belt
Insular Belt
British Columbia
Pacific Ocean
Washington
Overview Map
British Columbia
Legend
Simplified Bedrock Geology
sedimentary rocks
intrusive rocks
volcanic rocks
ultramafic rocks
metamorphic rocks
Tectonic Belts
0
60
120
240 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2006
Produced By: OHEB GIS Unit, DFO

Figure A.2 Bedrock geology simplified into basic rock types with tectonic belt boundaries superimposed (data from BC Ministry of Energy and Mines, updated 2005).

The **Intermontane Belt,** is a low relief, high elevation area made up of high plateaus and rolling uplands situated between two mountainous belts (Coast and Omineca). The belt is made up of three major exotic terranes (Figure A.3) dominantly made up of marine volcanic and sedimentary rocks of Devonian to Jurassic age, which formed before the terranes amalgamated (by the middle Jurassic) and subsequently docked with North America. These rocks are overlain by Jurassic and Cretaceous clastic wedges and flat lying Tertiary volcanic and sedimentary rocks which were laid down during and after accretion of the terrane. These latter two rock types dominate the geologic map (Figure A.2) as they are the rocks most commonly found exposed at the surface.

The **Coast Belt** is dominated by granitic and metamorphic rocks. The belt likely formed as a result of long-term subduction, and the accretion, and form a suture zone (roughly the glue) between terranes. Heat and pressure associated with this subduction caused the metamorphism of existing sedimentary and volcanic strata. The Coast Belt is made up of roughly 80% granitic intrusions (Figure A.2) and forms one of the largest granitic masses in the world generally called the 'Coast Plutonic Complex'. The granites are formed deep in the earth, likely as the roots of volcanoes, and were uplifted and exposed by tectonism and erosion in Cenozoic time, giving BC's mainland coast its distinctively steep and rugged topography. These granitic and metamorphic rocks are dominantly Jurassic to Tertiary in age and overly volcanic and sedimentary rocks dating back to the middle Paleozoic (FigureA.2).

The **Insular Belt** includes the rocks of the Queen Charlotte and Vancouver islands and the submerged bedrock of the continental shelf out to the toe of the slope (PNCIMA's western boundary). The Insular Belt is similar to the Intermontane Belt in that it is a composite of terranes and is dominated by volcanic and sedimentary rocks that formed in marine volcanic arcs and basins ranging in age from the Upper Cambrian to the Tertiary. The terranes probably amalgamated in Middle Jurassic time and collided with the Intermontane Belt during the Cretaceous. Sub-marine portions of this belt are dominated by thick sedimentary successions and volcanics of Tertiary age (see section 1.2 and Figure A.2).

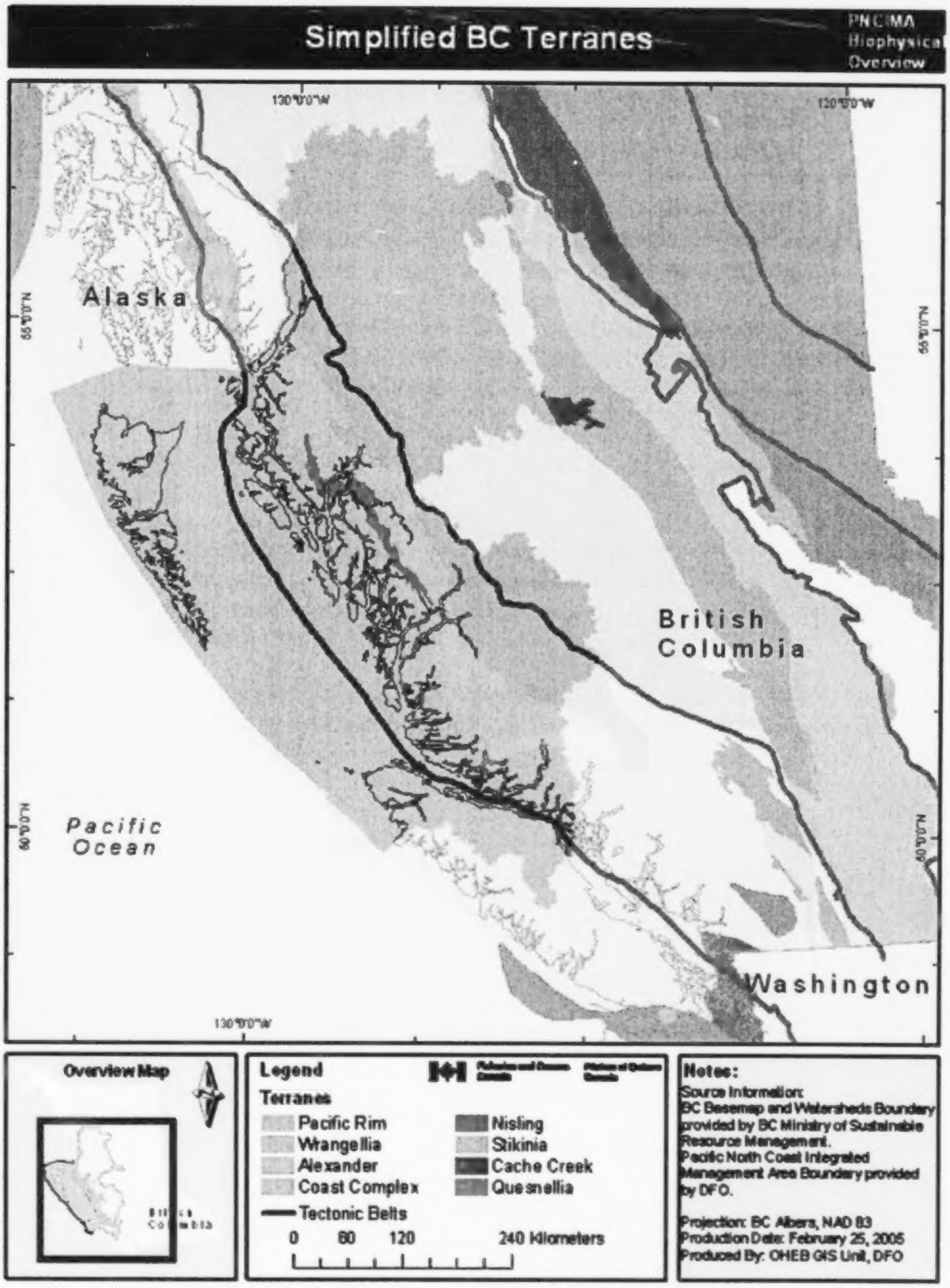

Simplified BC Terranes
PNCIMA
Biophysical
Overview
130°0'0"W
120°0'0"W
55°0'0"N
50°0'0"N
Alaska
British
Columbia
Pacific
Ocean
Washington
Overview Map
British
Columbia
Legend
Terranes
Pacific Rim
Wrangellia
Alexander
Coast Complex
Nisling
Stikinia
Cache Creek
Quesnellia
Tectonic Belts
0
60
120
240 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.3 Simplified terranes of BC (data from the BC Ministry of Energy and Mines).

2.2 Plates, Faults, and Seismicity

Seaward of BC's continental margin there is a highly complex plate boundary produced by the meeting of tectonic plates moving in different directions (Figure A.4). Here, the meeting of the very large North American and Pacific plates with the Explorer plate (a very small remnant of a plate just north of the Juan de Fuca plate) results in a complex morphology. The meeting point of the three plates is called a triple junction, which accommodates the different plate movements in a complex combination of transform faults, spreading ridges, and a subduction zone. South of this triple junction is the subduction zone resulting from the Juan de Fuca and the Explorer plates (dense oceanic crust) sliding beneath the North American plate (less dense continental crust). North of the triple junction is a transform or strike-slip fault known as the Queen Charlotte Fault Zone and which is similar in nature to the San Andreas Fault in that the two plates here are sliding past one another.

Each of these three zones produces slightly differing earthquake environments that contribute to the offshore seismic hazard in this region (Figures A.5-A.7). The world's largest earthquakes occur in subduction zones. When the oceanic crust being subducted is very young and hot, the subduction zones become locked for long periods of time and produce only very large earthquakes rather than a continuous size range of earthquakes.

The Cascadia subduction zone along the coast of southwestern BC and western USA is of this type and produces 'giant megathrust earthquakes' (magnitude greater than 8) (Hyndman *et al.* 1999) at intervals of several centuries. Paleoseismic evidence suggests that such giant earthquakes have occurred here many times in the past, and the most recent one was about 300 years ago (Figure A.5, black circle). The subducting Juan de Fuca plate is currently locked with the North American plate along its entire length from BC to California (Hyndman *et al.* 1999). There is abundant lower magnitude seismicity also found in the region of subduction plates (Figure A.7), however, this seismicity is the result of failure along smaller faults within either the overlying continental crust or the underlying ocean plate. This occurs as a result of the deformation of the plates as their overall movement continues despite the subduction fault being locked. Transform faults like the Queen Charlotte Fault Zone and the famous San Andreas Fault, mark the boundaries where tectonic plates slide past one another. This is expressed as a zone of deformation and seismicity where mechanisms for earthquakes and observed relative motions along any fault strand may be complex. The two sides of the fault become locked together at various places along the fault. As the plates continue to move, the locked areas accumulate stress until they fail, releasing the stress as an earthquake. Transform faults are associated with some of the most seismically active areas in the world. They produce a range of earthquakes from very frequent low magnitude events to larger, potentially damaging events, normally in a complex zone surrounding the transform margin (magnitude 6-8, Figures A.5-A.7). As the earthquakes get larger, the frequency of occurrence decreases at a predictable rate.

In the area of the triple junction itself, the complexity of the junction gives rise to a great many small faults. The result of this and the stresses placed upon this region in accommodating the movements of the three plates, is that seismic activity is very high, but individual events are rarely of high magnitude. The occasional magnitude 7 earthquakes tend to be the strongest recorded in this area (Figures A.5-A.7).

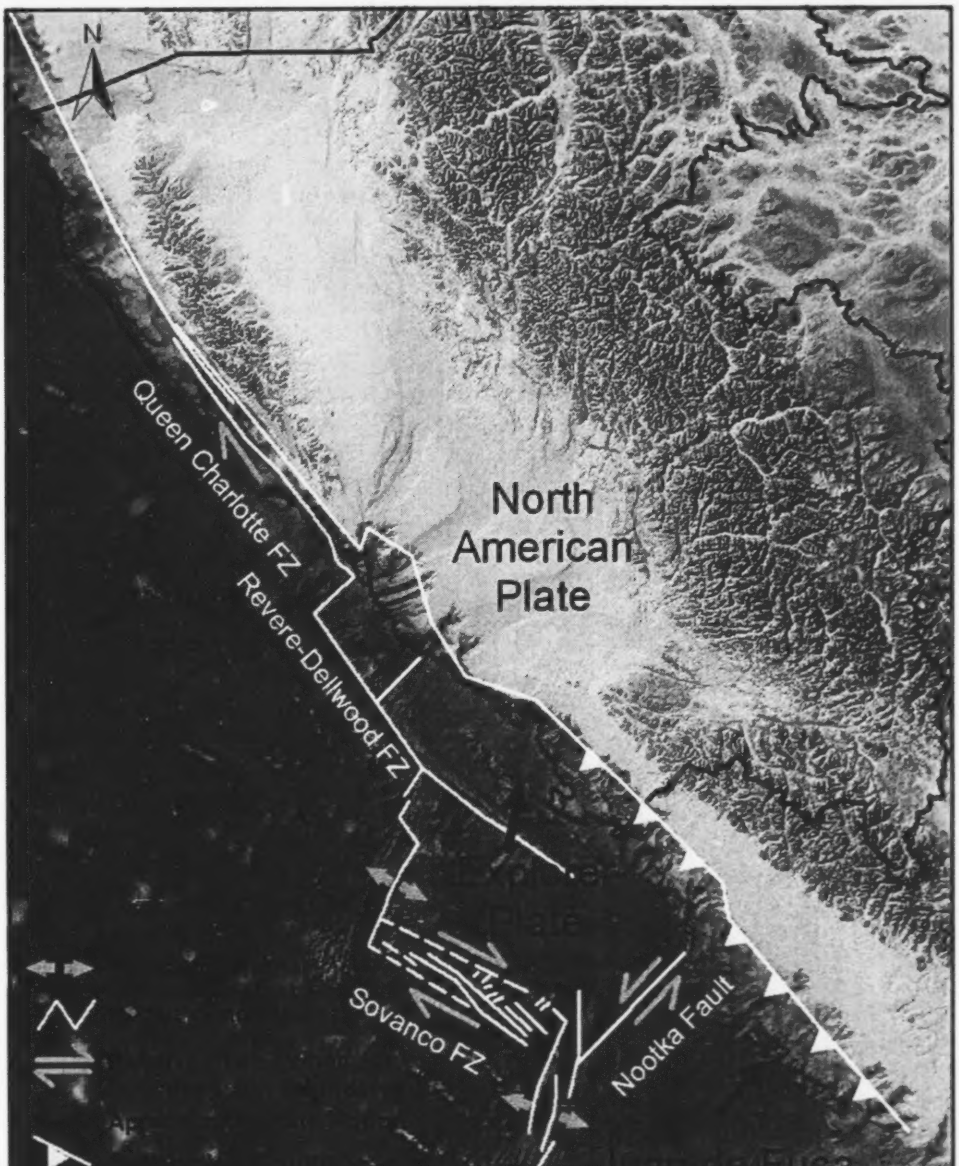

N
Queen Charlotte FZ
Revere-Dellwood FZ
North American Plate
Explorer Plate
Sovanco FZ
Nootka Fault
Juan de Fuca Plate
100
0
100
200 Kilometers

Figure A.4 Plate boundaries and relative plate motion off the coast of BC (data from Natural Resources Canada).

but individual events are rarely of high magnitude. The occasional magnitude 7 earthquakes tend to be the strongest recorded in this area (Figures A.5-A.7).

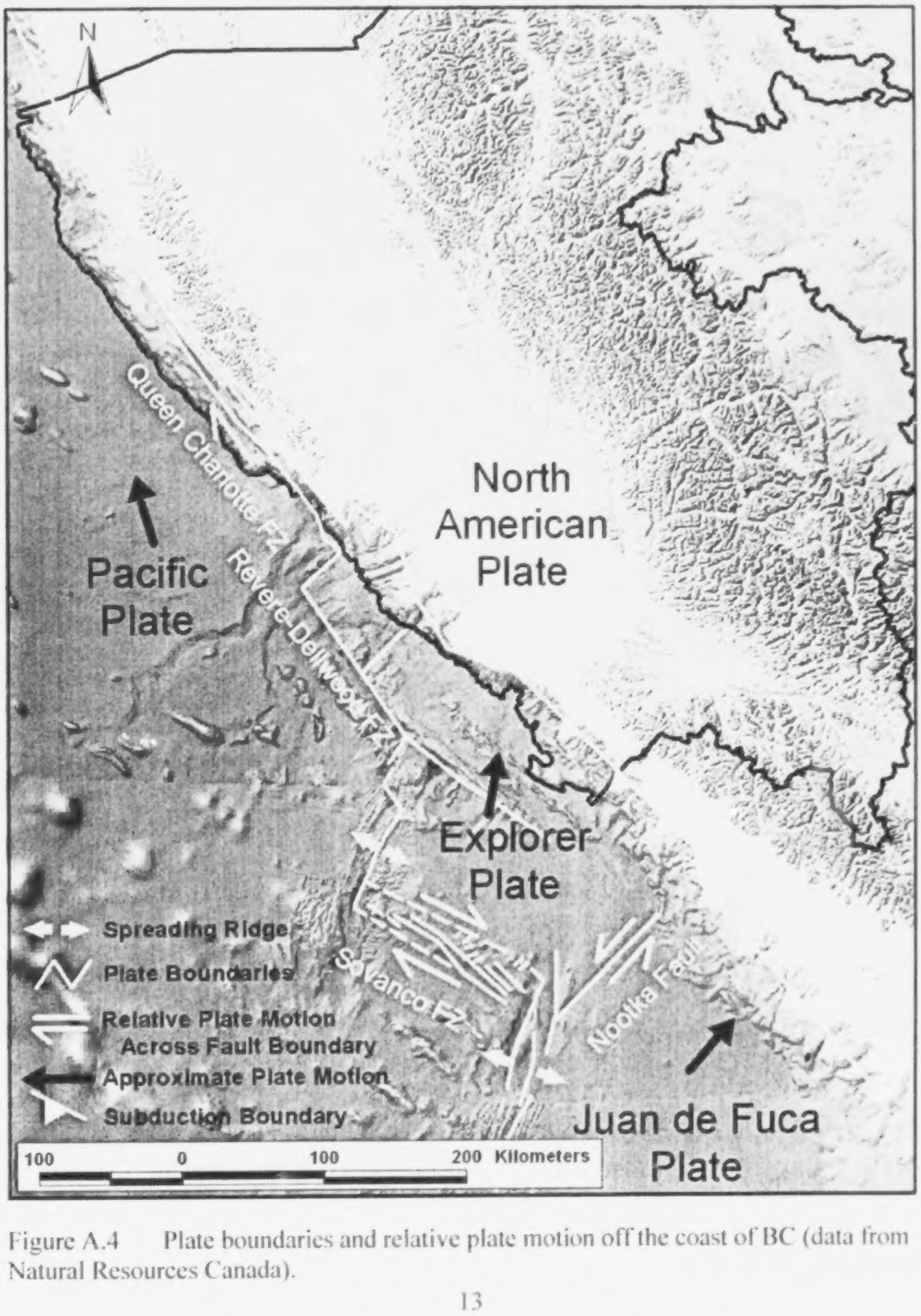
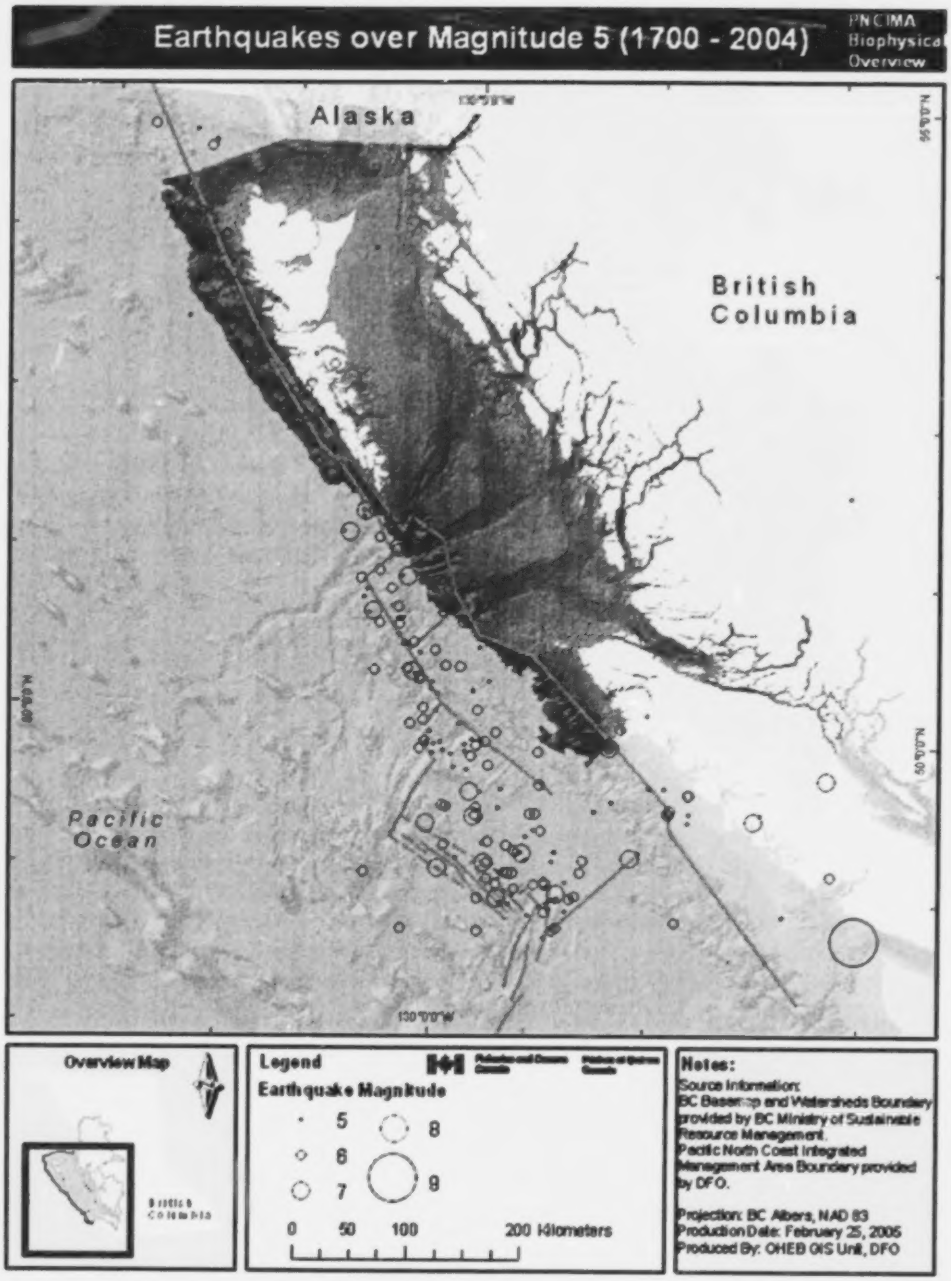

N
Queen Charlotte FZ
Revere-Dellwood FZ
Sovanco FZ
Nootka Fault
North American Plate
Pacific Plate
Explorer Plate
Juan de Fuca Plate
Spreading Ridge
Plate Boundaries
Relative Plate Motion Across Fault Boundary
Approximate Plate Motion
Subduction Boundary
100
0
100
200 Kilometers

Figure A.4 Plate boundaries and relative plate motion off the coast of BC (data from Natural Resources Canada).


Earthquakes over Magnitude 5 (1700 - 2004)
PNCIMA
Biophysical
Overview
Alaska
British
Columbia
Pacific
Ocean
130°0'0"W
55°0'0"N
50°0'0"N
Overview Map
British
Columbia
Legend
Earthquake Magnitude
5
6
7
8
9
0
50
100
200 Kilometers

Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.

Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.5 All recorded earthquake events along the BC coast of magnitude 5 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre).

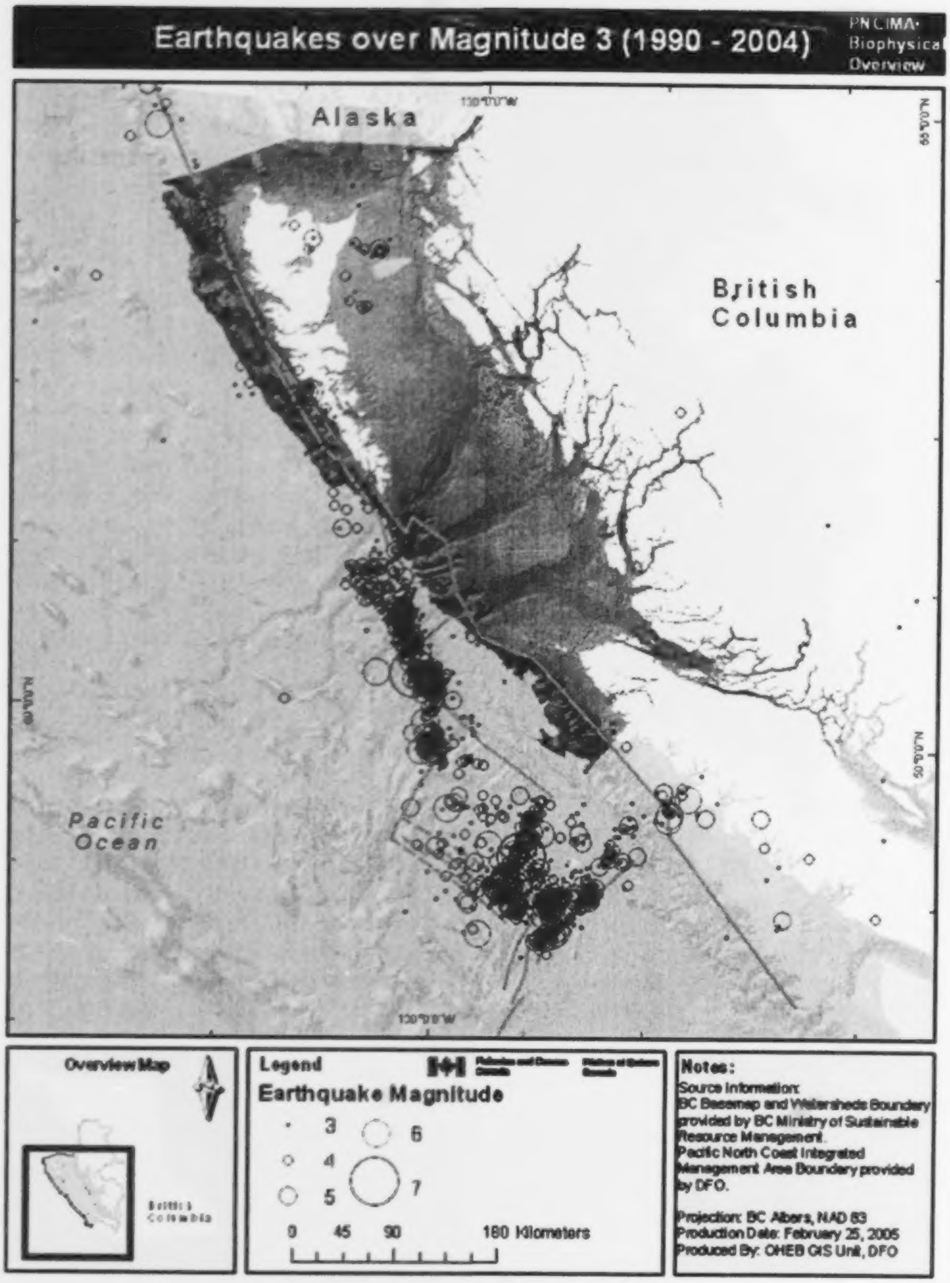

Earthquakes over Magnitude 3 (1990 - 2004)
PNCIMA·
Biophysical
Overview
Alaska
British
Columbia
Pacific
Ocean
55°0'0"N
50°0'0"N
130°0'0"W
Overview Map
British
Columbia
Legend
Earthquake Magnitude
3
4
5
6
7
0
45
90
180 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.6 15 years (1990-2004) of recorded earthquake events along the BC coast of magnitude 3 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre 2005).

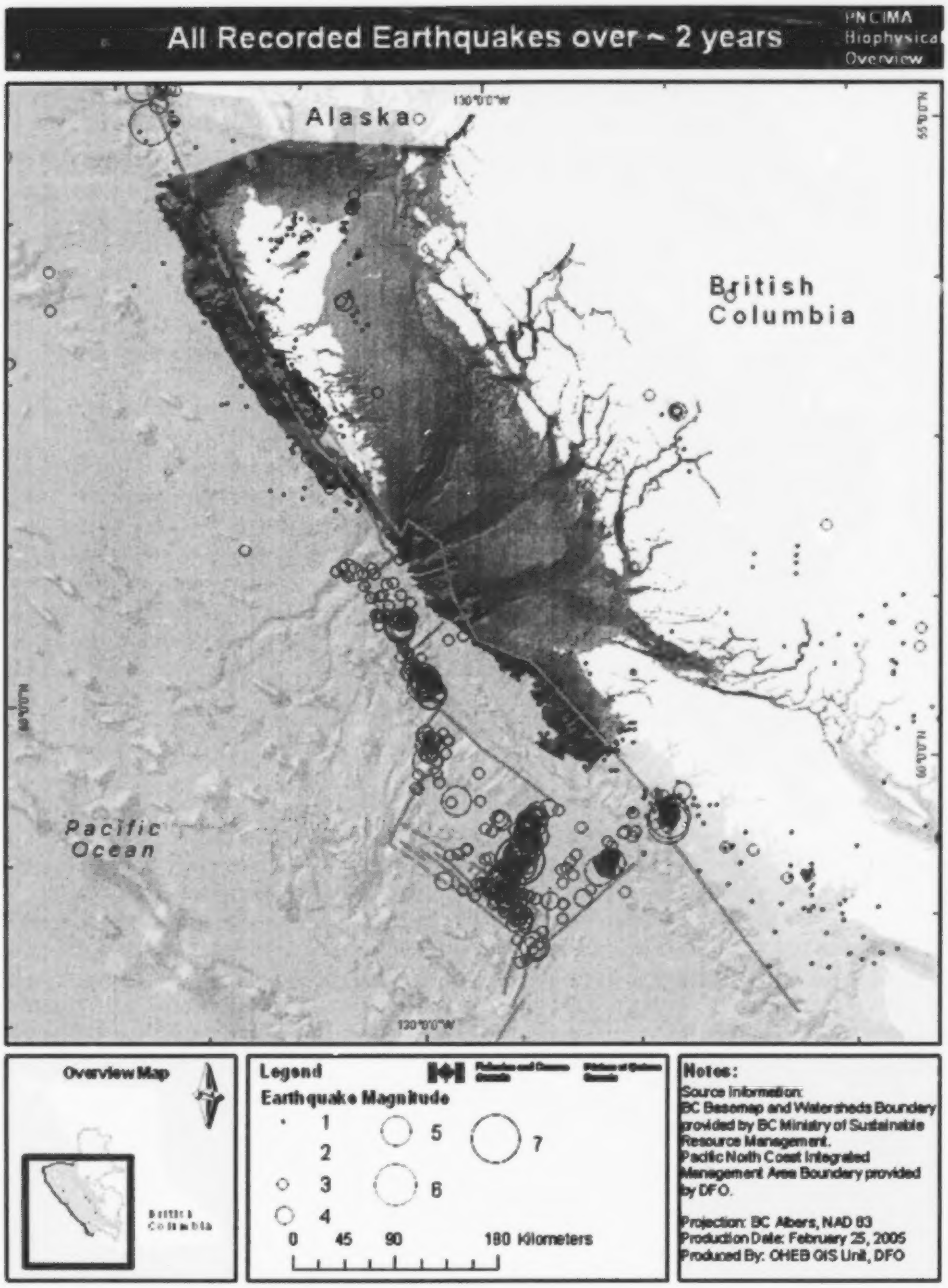

All Recorded Earthquakes over ~ 2 years
PNCIMA
Biophysical
Overview
Alaska
British
Columbia
Pacific
Ocean
130°0'0"W
55°0'0"N
Overview Map
British
Columbia
Legend
Earthquake Magnitude
1
2
3
4
5
6
7
0
45
90
180 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.7 23 months (Jan 2003-Nov 2004) of recorded earthquake events along the BC coast of magnitude 1 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre).

3.0 GEOMORPHOLOGY

3.1 Quaternary Glaciation

The Quaternary Period is the most recent geological period, dating from approximately 2.4 million years ago to the present. The geological processes that took place in this period sculpted the landscapes whose basic forms were produced by the tectonic events described in section 2.2. Since each glaciation tended to remove or re-work features created by the previous one, most existing glacial features are the result of the most recent glaciation, the Wisconsinan. British Columbia differs somewhat from central and eastern North America in that glaciation consisted of the growth and amalgamation of numerous piedmont glaciers of the Cordilleran Ice Sheet. The local timing of growth and decay differs slightly from that of the Laurentian Ice Sheet due to differences in the climatic influences west of the Rocky Mountains.

The most recent glacial advance is locally referred to as the Fraser Glaciation. During this time period the pronounced glacial geomorphology and surficial materials distribution found throughout British Columbia were developed. This glacial geomorphic heritage includes diverse submarine features directly related to the extensive Fraser Glaciation. Figure A.8 illustrates the current understanding of the maximum extent of the late Wisconsinan (Fraser) glaciation, which is thought to have reached this maximum sometime after 21,000 yr BP (years before present) (Blaise *et al.* 1990) and before the initiation of rapid retreat ~ 15,000 yr BP (Barrie and Conway 2002).

The submarine troughs on the continental shelf in Queen Charlotte Basin are thought to have been filled by piedmont lobes of this glaciation (Josenhans *et al.* 1995), possibly extending to the shelf break although the extent is uncertain for Moresby Trough. Lobate ice masses develop where ice from steep terrain flows out onto a low gradient landscape or plain. Evidence also suggests that the southern portion of the Queen Charlotte Islands and the tip of Brooks Peninsula may have remained ice-free thus providing refugia for plant and animal species that would not have survived a more complete ice coverage. Recently research has focussed on the distribution of ice free land, the organisms there and the timing of glacial events (Hetherington 2002; Josenhans *et al.* 1995; 1997).

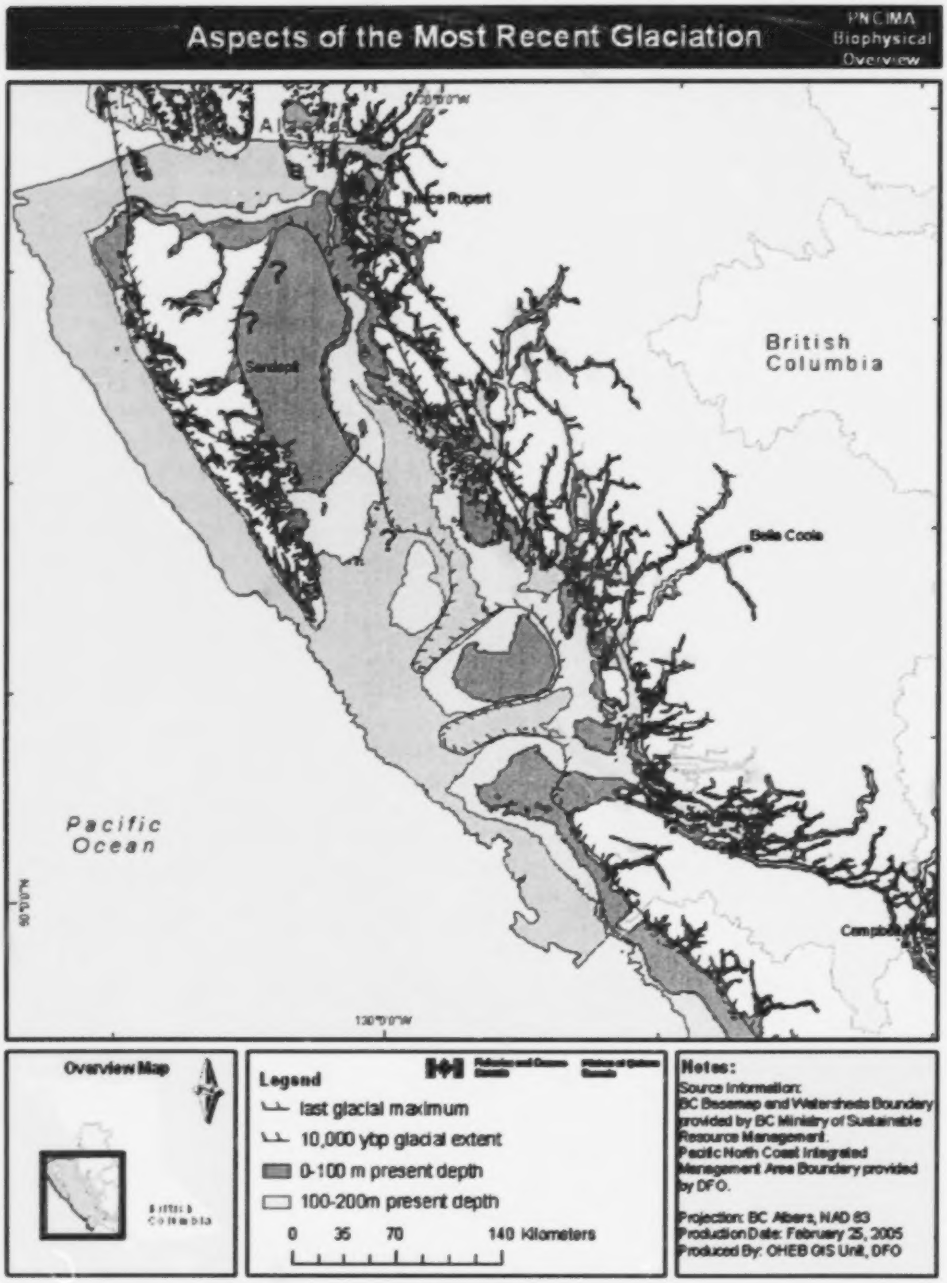

Aspects of the Most Recent Glaciation
PNCIMA Biophysical Overview
Alaska
130°0'0"W
Prince Rupert
?
?
Sandspit
British Columbia
Bella Coola
Pacific Ocean
Campbell
50°0'0"N
130°0'0"W
Overview Map
British Columbia
Legend
last glacial maximum
10,000 ybp glacial extent
0-100 m present depth
100-200m present depth
0 35 70 140 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.8 Map of the approximate location of the last glacial maximum (modified from Blaise *et al.* 1990; Josenhans *et al.* 1995) and the extent of glaciation during retreat at approximately 10,000 year before present (based on Josenhans *et al.* 1995). Question marks denote poor constraint of glacial maximum.

The paleo-oceanography of the PNCIMA region has been studied through the examination of sediment cores and relating the contained microfossil assemblages to oceanographic conditions on the shelf. Oceanographic and tidal currents and therefore water circulation on the shelf would have changed markedly during the physiographic and climate changes that drove and accompanied the sea level changes described below. Examination of this microfossil record indicates that by 10,000 years before present shelf bottom water temperatures were similar to today (Guilbault *et al.* 1997). Details of the oceanographic changes that accompanied deglaciation of the shelf have been illuminated (Guilbault *et al.* 1997) including events such as the Younger Dryas, a rapid cooling event at the end of the Fraser glaciation (Patterson *et al.* 1995). A large-scale outburst flood event that occurred during the deglaciation of the southern BC hinterland in the Fraser River watershed when an ice dam or dams was breached has been observed in cores (Conway *et al.* 1991). This event affected all the waters of the Georgia Basin and would therefore have affected the southern portion of PNCIMA. Details of oceanographic changes that affected the southernmost portion of PNCIMA are presented in Guilbault *et al*. (2003).

Ice loading on the Earth's crust results in depression of the land surface. This is known as glacio-isostatic depression. As glaciers build over an area, they depress the underlying crust lower down into the viscous mantle. The load is transmitted through the upper part of the mantle to push material away from the load and elevate the land surface. This elevated land, peripheral to the ice load, is called a proglacial forebulge and was a large factor in the sea-level history on the BC margin. Another important factor is the removal of water from the oceans of the world to form the continental ice sheets and mountain glaciers which is termed eustatic sea level lowering. This factor contributed up to 110 m of sea level lowering globally during the last glacial maximum 15,000 years ago (Fairbanks 1989).

Relative sea level results from the interplay between isostatic, eustatic and other factors, including tectonism, and is therefore locally quite variable and complex in timing and magnitude at any given location. As ice began to retreat ~ 15,000 yr BP, it retreated most rapidly proximal to the Pacific Ocean. Between 13,000 to 10,000 yr BP, ice was still thick over mainland BC, but had retreated from most of the continental shelf (Josenhans *et al.* 1995; Barrie and Conway 2002). The weight over the mainland, coupled with release of weight over the shelf, caused the shelf area to bulge upwards significantly. It is thought that this proglacial forebulge, combined with global eustatic sealevel lowering caused much of the shelf to be exposed from between 100 and 200 m below current sea level. Figure A.8 shows the area that would likely have been exposed at 100 m of relative sealevel lowering (dark grey). The bulge had a wavelength such that greater uplift occurred further from the mainland.

Fjords along the mainland experienced higher relative sealevels, as illustrated by paleoshorelines found near Kitimat that are now 200 m above sea level (Clague 1985). At the same time, areas of the continental shelf experienced relative sealevels lowered by as much as 200 m and submerged paleoshorelines may be observed, sampled, and radiocarbon dated across much of the region (Luternauer *et al.* 1989a). As the glaciers retreated and ice melted, more sediments were deposited, and meltwater re-worked much of this sediment on the temporarily emergent shelf. The uplifted continental shelf allowed for much of this re-working, and waves and beach processes remobilized and transported sediments that are now in relatively deep water. The landscapes and seascapes described below, and the distribution of the unconsolidated sedimentary deposits both on land and on the continental shelf, are in large part a result of the last glaciation, and associated sealevel changes.

3.2 Topography of Coastal Landscapes

The coast of BC is made up of three broad physiographic features, (Figure A.9), the Insular Mountains, the Coastal Trough, and the Coast Mountains. The upper portions of PNCIMA watersheds also extend into the Interior Plateau. Along the outer coast, the Insular Mountains consist of the relatively low lying, glaciated mountain ranges of Vancouver Island and the Queen Charlotte Islands. Eastward of these mountains is the Coastal Trough made up of the Hecate and Georgia depressions, including the seafloor of Hecate Strait, through Queen Charlotte Sound and Johnstone Strait to the Strait of Georgia and the lowland areas adjacent to these water bodies. These low-lying basins are adjacent to the Coast Mountains which are steep sided, granite cored mountains. On the far side of these mountains lies the Interior Plateau which consists of high elevation but low relief plains and rolling hills. This pattern of mountains, trough, mountains, plateau is the result of the tectonic forces acting on the Earth's crust caused by the subduction of the Pacific sea floor beneath the North American plate (Thomson 1981) as described in section 2.2.

Glaciation has cut deep, U-shaped valleys into the Coast Mountains, many of which have become long, narrow, steep sided fjords. The resulting coastline is very rugged and mostly inaccessible from the east. Communities are accessed by water and are generally forced to be near the shore since most of the inland area is too steep to use or build on, with the exception of the upper end of the larger fjords.

Clague and Bornhold (1980) provide a detailed summary of the littoral processes affecting the BC coast and a discussion of the resulting coastal landscapes and shoreline types. They note that, although there are a variety of energy levels found along the coast, ranging from the very high energy areas of the exposed coast to low energy protected channels, straits, inlets and fjords, the dominance of resistant rock types along the coast coupled with very low input of terrestrial sediments results in little or no littoral sediments in most areas. The lack of sediment input is a result of the relatively few large rivers emptying into the coastal waters, and the presence of deep fjords or basins which allow settling of much of the sediment before it can reach the outer coast. The result is a coastline dominated by rocky shorelines with rare and generally small pockets of gravel or sand beaches which are mostly found along the lowlands of the Coastal Trough or places where cliffs of glacial sediments are actively eroding and providing an ongoing source of sediments.

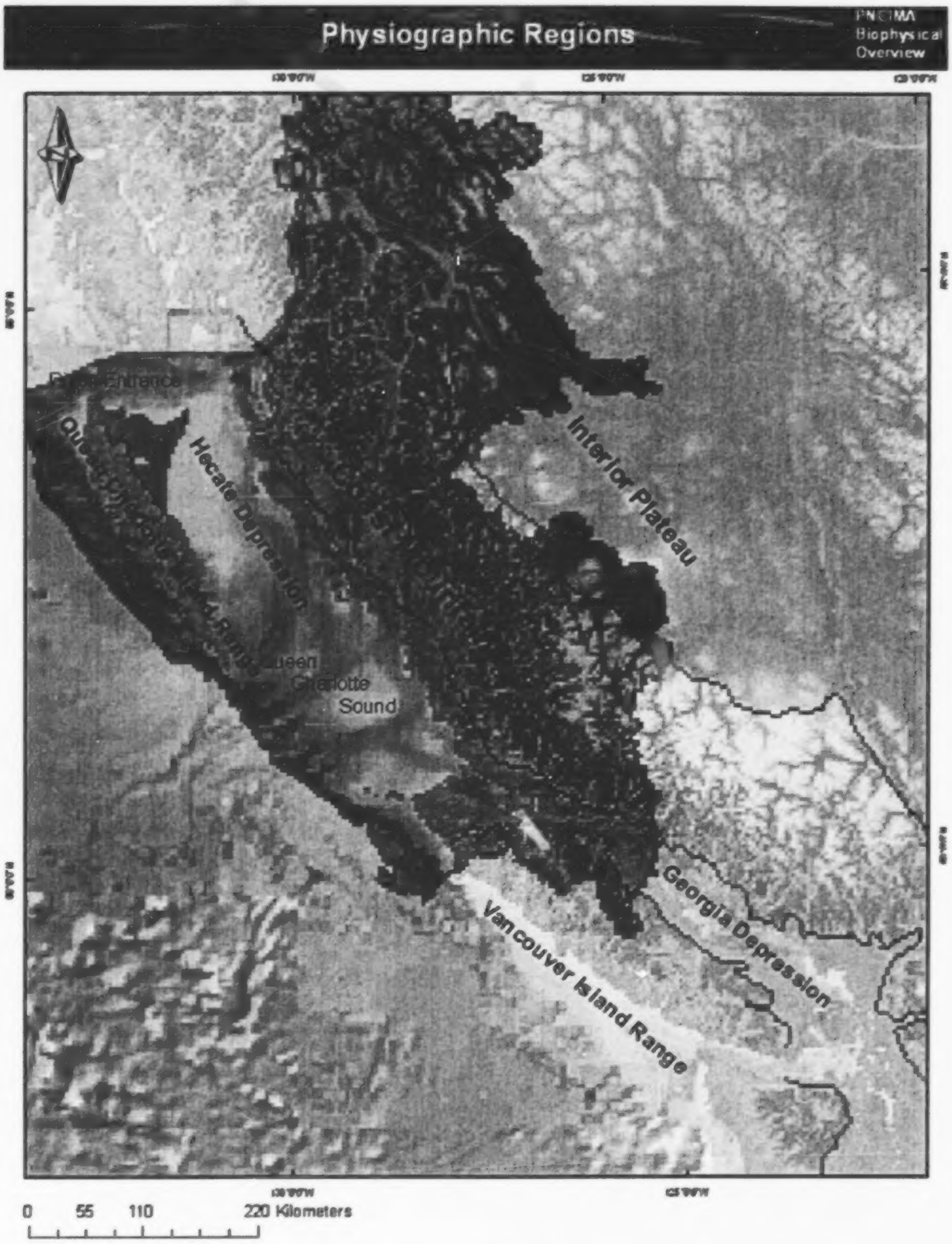

Physiographic Regions
PNCIMA
Biophysical
Overview
Dixon Entrance
Queen Charlotte Island Range
Hecate Depression
Queen Charlotte Sound
Interior Plateau
Georgia Depression
Vancouver Island Range
0
55
110
220 Kilometers

Figure A.9 Physiographic regions of Coastal BC. Topographic and bathymetric image from Natural Resources Canada (regions adapted from Clague and Bornhold 1980; Thomson 1981).

The provincial government, in association with Coastal and Ocean Resources Inc., has produced GIS data of shoreline types for the entire BC coastline based on the analysis of video footage taken from flights over the shorezone. These data are most useful at a fine scale and are being made publicly available via http://maps.gov.bc.ca/imf406/imf.jsp?site=dss_coastal.

3.3 Watersheds and Hydrology

PNCIMA includes a portion of what is termed the Coastal Drainage, one of the nine drainage basins of BC, as well as the drainage basins of the Skeena and Nass rivers and the small island drainages. These drainage basins are divided into Major Watersheds which are in turn subdivided into the Watershed Groups as illustrated in Figure A.10. These watershed divisions are commonly used in terrestrial planning and management processes at all levels of government.

The majority of PNCIMA receives limited fresh water from relatively short, steep coastal drainage basins or from extremely short and relatively low lying drainage basins found on the Queen Charlotte and Vancouver islands. This is in sharp contrast with the Strait of Georgia to the south which is strongly influenced by the huge Fraser River drainage basin (Figure A.11). However, the northernmost portion of PNCIMA (Dixon Entrance) receives significant fresh water from the Skeena and Nass drainage basins. Figure A.12 shows that these drainage basins produce about 1/3 the volume of the Fraser River.

Figure A.12 also shows the hydrographs of selected rivers, which appear to fall into three types reflecting the hydrodynamics of their watershed. The first type is the snowfall dominated rivers. This is reflected in the larger rivers (Skeena, Nass and Fraser) which generally achieve their highest flows during spring freshet due to the initial melt of the snow pack, and their flow rates taper off through the summer. This is likely seen in the larger rivers because of the large surface area of their drainage basins allowing them to accommodate large volumes of snow. Flows for these rivers decrease during the fall (with some peaks for fall storms) and are generally lowest in the winter when much of their watershed is cold enough to be accumulating snow.

The rainfall dominated rivers show almost the opposite trend in that their highest flows are during the fall and winter storm seasons while spring and summer show a steady decrease in flow volume. The small and low elevation watersheds of the Queen Charlotte and Vancouver islands tend to produce rainfall dominated rivers, especially as they receive less overall precipitation and temperatures are made so mild by the influence of the ocean that they accumulate relatively little snow.

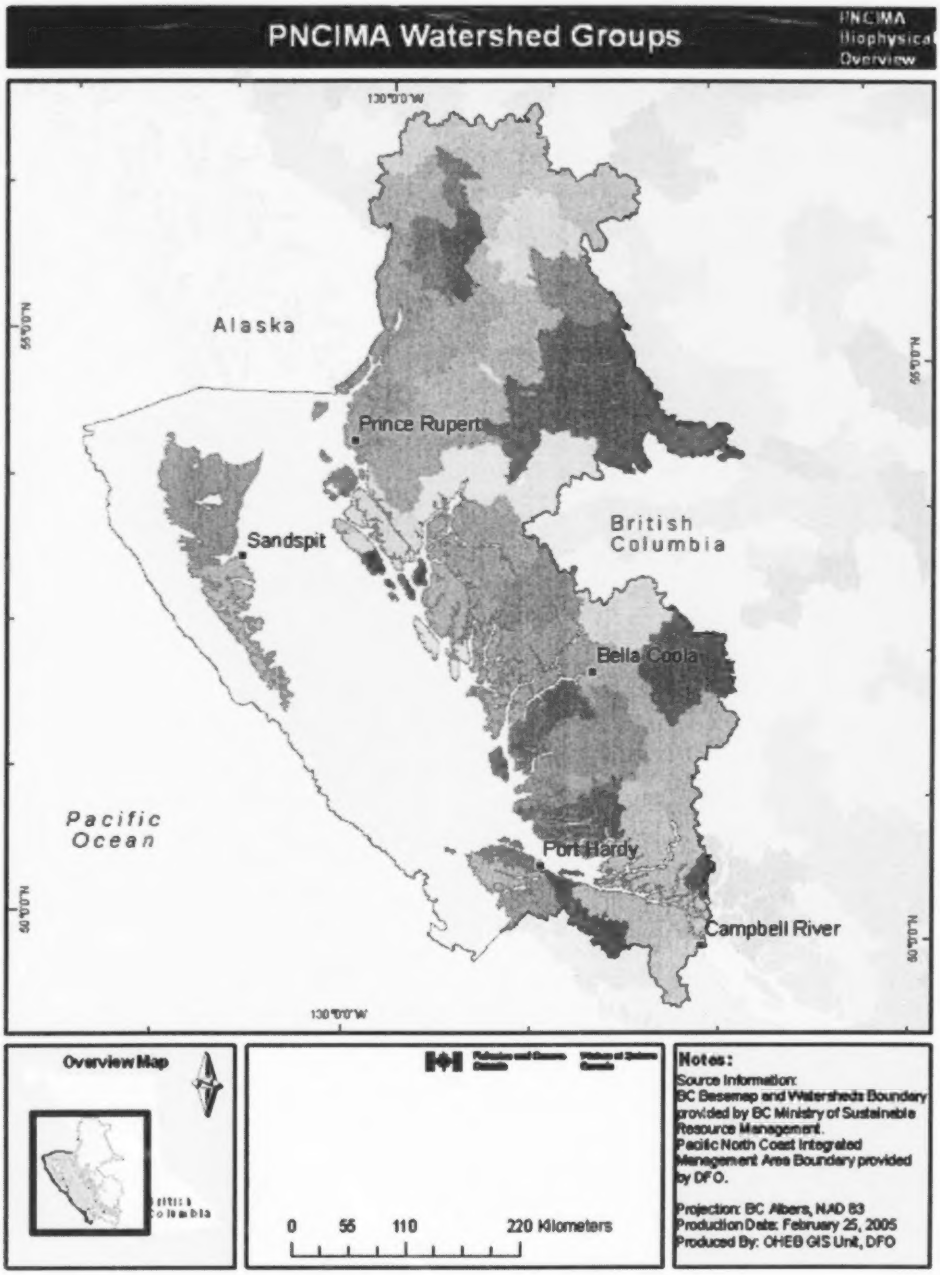

PNCIMA Watershed Groups
PNCIMA
Biophysical
Overview
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Prince Rupert
Sandspit
British Columbia
Bella Coola
Pacific Ocean
Port Hardy
Campbell River
Overview Map
British Columbia
0
55
110
220 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.10 Watershed Groups in PNCIMA (data from the BC Ministry of Sustainable Resource Management, Digitized from Environment Canada map sheets).

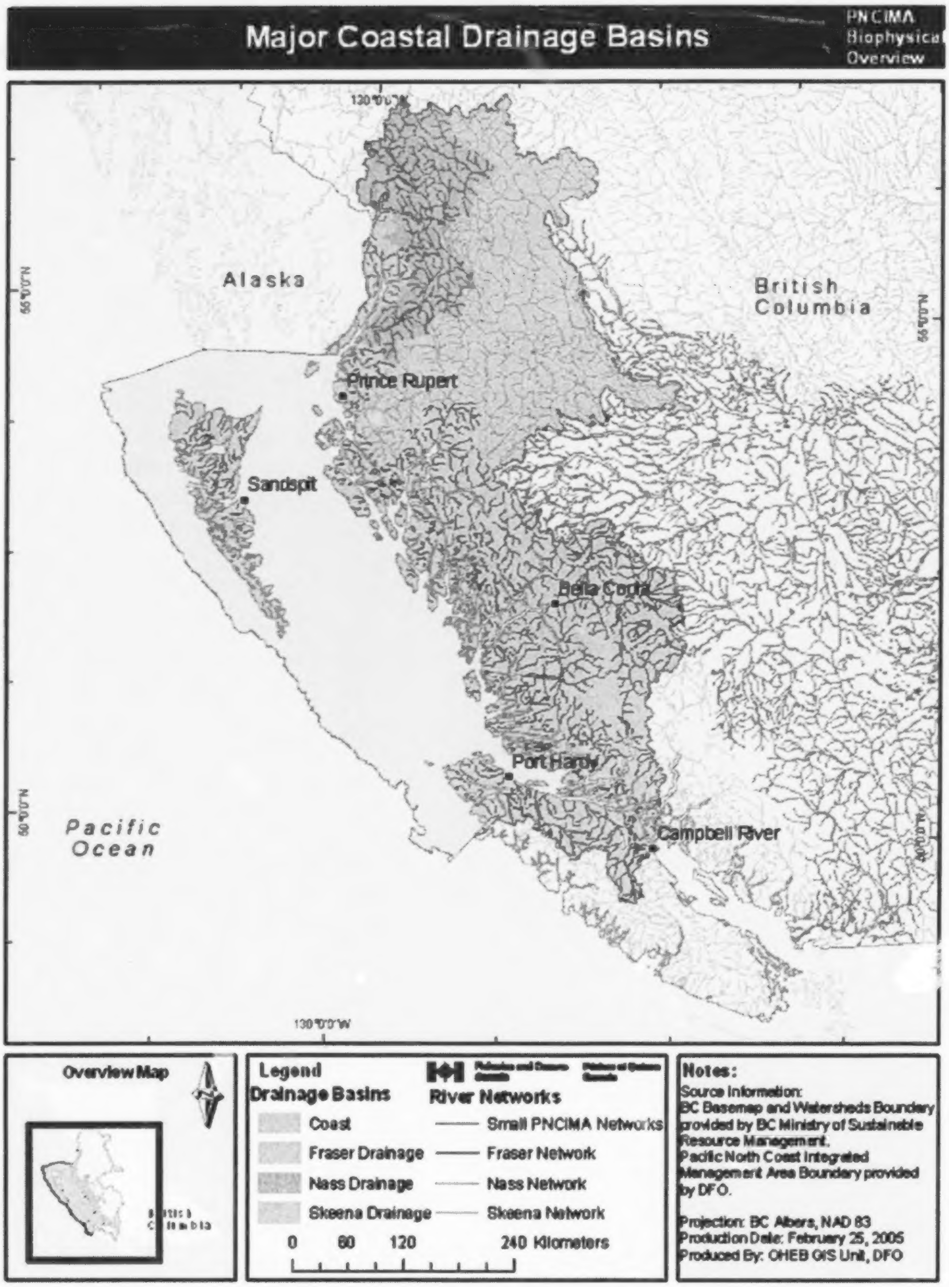

Major Coastal Drainage Basins
PNCIMA Biophysical Overview
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
British Columbia
Prince Rupert
Sandspit
Bella Coola
Port Hardy
Campbell River
Pacific Ocean
Overview Map
British Columbia
Legend
Drainage Basins
Coast
Fraser Drainage
Nass Drainage
Skeena Drainage
River Networks
Small PNCIMA Networks
Fraser Network
Nass Network
Skeena Network
0
60
120
240 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.11 PNCIMA drainage patterns and adjacent major drainages (data from the BC Ministry of Sustainable Resource Management and Natural Resources Canada).

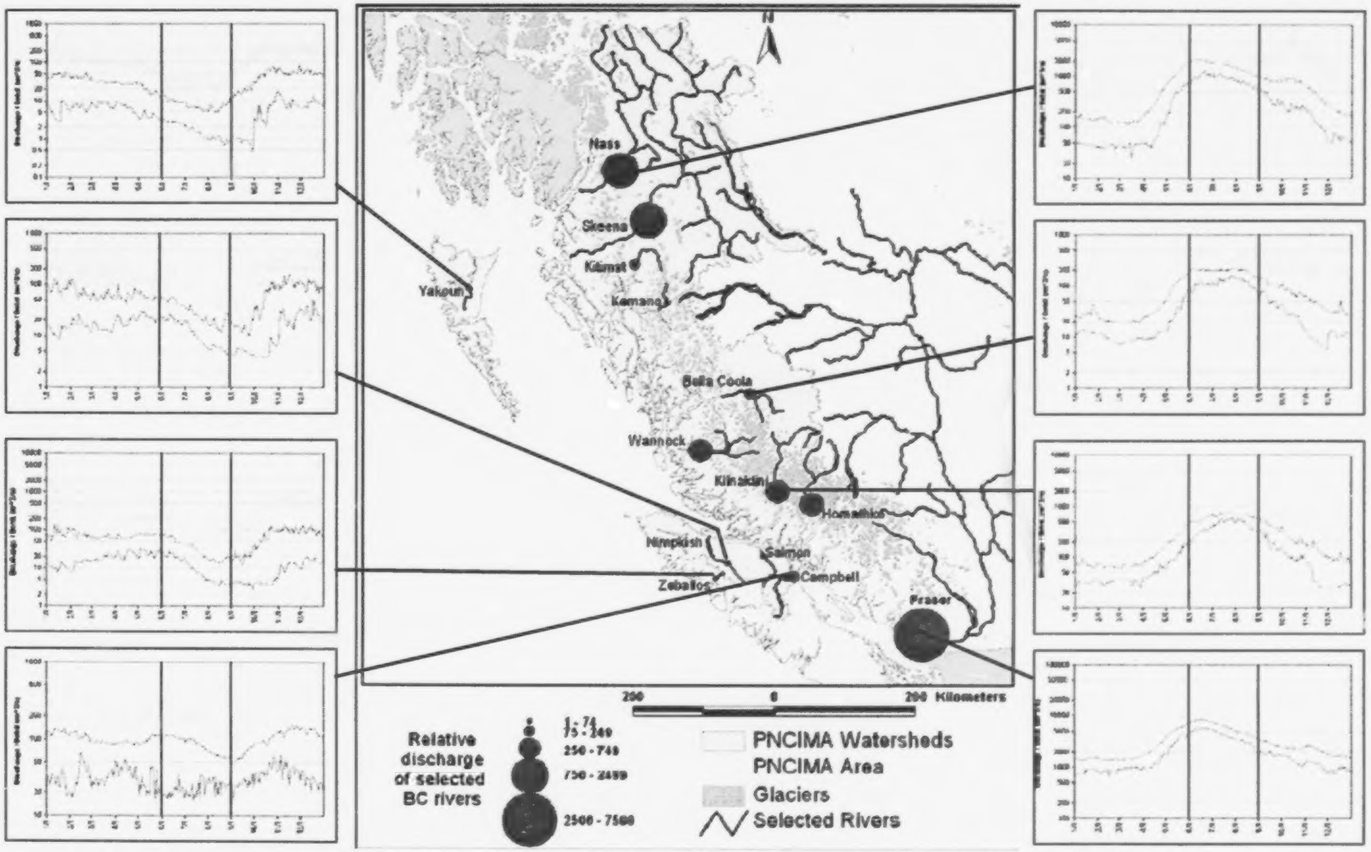

N
Nass
Skeena
Kitimat
Kemano
Yakoun
Bella Coola
Wannock
Klinaklini
Homathko
Nimpkish
Salmon
Campbell
Zeballos
Fraser
200 0 200 Kilometers
Relative discharge of selected BC rivers
1 - 74
75 - 249
250 - 749
750 - 2499
2500 - 7500
PNCIMA Watersheds
PNCIMA Area
Glaciers
Selected Rivers

Figure A.12 Maximum (green curve), mean (blue curve) and minimum (red curve) average annual river discharge from selected rivers of Coastal BC and hydrographs of their seasonal discharge (for details of discharge see http://scitech.pyr.ec.gc.ca/climhydro/welcome_e.asp, discharge data from Environment Canada's HYDAT CD ROM).

A third hydrograph pattern arises with the rivers of the central portion of the coast. These rivers experience the spring freshet as their steep watersheds would be capable of accumulating significant snowfall at high elevations. However, throughout the summer there is little or no slackening of flow volumes and in some cases there is slight increase with warmer late summer weather (see Klinaklini in Figure A.12). This is likely a result of the abundant and large glaciers found at the heads of the central coast watersheds which would achieve peak melt during the hottest part of the summer. Because their drainage basins are small, the effect of the glaciers is not lost in comparison to a huge snowmelt in the spring. A further result of their lower overall flow volumes is that the effect of fall and winter storms on the hydrograph is more pronounced compared to larger rivers.

Two important points arise from this hydrologic information. Firstly, freshwater influence is very significant to physical oceanographic processes and biological productivity (as discussed in Appendices C and D). This suggests that there may be significant differences between the northernmost portion of PNCIMA with its stronger, spring timed freshwater influence, as compared to the south and central portions with lower overall flows and more steady rates throughout the summer.

Secondly, if climate change progresses as is predicted (see discussion in Appendix B), one significant change to freshwater flows would be a change in the hydrologic profile of some of these rivers. Two consistent changes have been noted in northern BC rivers that are thought to be related to climate change (Whitfield 2003). One is that overall streamflows have increased. This is thought to be a result of higher temperatures causing melting of formerly permanent snow, ice or permafrost. This is necessarily a short term effect as once those reserves are used up, streamflows will decrease, possibly dramatically. At that point those streams will likely be more strongly influenced by rainfall than by meltwaters. Coastal streams in particular have shown increases in winter runoff and decreases in early spring and late summer discharge (Whitfield *et al.* 2003). The second effect is a steady movement of spring freshet to earlier and earlier peaks times. This would be due to increased temperatures causing earlier snowmelt. This may have significant impact on ecosystem function, particularly as it is often coupled with earlier and more extreme summer and fall minimum flows. Overall it was noted that changes in temperature is the main factor affecting stream flow, not changes in precipitation (Whitfield 2003).

Modelling has predicted two further effects of climate change on streamflow. There is expected to be an increase in the frequency, and for snowmelt dominated streams a summertime increase in magnitude, of flood events (Whitfield *et al.* 2003). Over a longer time scale, modelling of the Fraser River has suggested that by 2080 the Fraser River will behave as a rainfall dominated river for 13% of the years (Morrison *et al.* 2002). This is a very significant change and would undoubtedly have significant effects on the Strait of Georgia ecosystem. The Skeena and Nass rivers currently behave much like the Fraser River (snowmelt dominated) and so may experience similar changes which would affect the northern portion of PNCIMA significantly.

3.4 Bathymetry and Seascapes

The distribution of marine geoscience data is presented in Figures A.13 and A.14. These data bear on geomorphic and bathymetric understanding of the region as well as the glacial history and the geology of the seabed. They also illuminate where data gaps exist in the understanding of the geologic development of the region. The marine portion of PNCIMA includes waters overlying the central and northern continental shelf and slope of BC. This portion of the shelf is dominated by a series of shallow banks in the understanding of the geologic development of the region.

The marine portion of PNCIMA includes waters overlying the central and northern continental shelf and slope of BC. This portion of the shelf is dominated by a series of shallow banks separated by deep troughs (Figures A.15 - A.17). Goose Island and Cook banks are relatively shallow (< 100 m), while North Bank is deeper (< 200 m), and Dogfish Banks are very shallow (< 20 m). Moresby, Mitchell's and Goose Island troughs separate the four central banks with depths to approximately 400 m where they reach the continental slope. Dixon Entrance (Figure A.15) is a relatively deep portion of the shelf open to the Pacific Ocean but submarine sills formed by igneous bedrock are transverse features within the trough that likely play an important role in deflecting bottom currents. The steep and rugged continental slope is included in PNCIMA, whose westernmost boundary is at the base of the slope as defined by the slope analysis of Jeff Ardron (Johannessen *et al.* 2004).

Medium-scale features on the continental shelf seafloor have been studied and mapped (Barrie *et al.* 1988; Luternauer *et al.* 1989b; Moslow *et al.* 1991; Barrie *et al.* 1990a; 1990b; 1990c; 1991a; 1991b; Barrie 1988; Bornhold and Barrie 1991; Barrie and Conway 2001). The most recent compilation of these seafloor features is shown in Figure A.17. Detailed seabed survey work in the mid 1980s resulted in the discovery of huge siliceous sponge reefs (Hexactinellida) in the troughs of Queen Charlotte Sound and Hecate Strait (Figures A.18 and A.19)(Conway *et al.* 1991; DFO 2002; GSC 2001a; 2001b). The BC sponge reefs are thought to be unique in the modern world, although the reef forming order of sponges, the Hexactinosida, built extensive reefs during the Upper Jurassic until the Late Cretaceous (between 150 and 65 million years ago)(Conway *et al.* 1991). These rare cold water reefs are now believed to be significant habitat for many marine organisms, particularly rockfish, and may be especially important during early life stages (Conway 1999; Jamieson and Chew 2002). Further research has recently been focused on the oceanographic setting (Conway *et al.* 2005a; 2005b; Whitney *et al.* 2005) and the ecology of the reefs (Cook 2005).

New survey and mapping techniques, particularly multibeam sonar, are allowing the high resolution mapping and characterization of the seabed. Collaboration between researchers with GSC and the Canadian Hydrographic Service (CHS) is producing high-resolution bathymetry and backscatter datasets within PNCIMA. The distribution of sponge reefs in the four main reef complexes has been defined by multibeam surveys (Figure A.17)(Conway *et al.* 2005a).

Multibeam swath bathymetry surveys require extensive survey ship time, so the mapping of the entire continental shelf of BC will require several years of sustained effort. The areas within PNCIMA that have been surveyed to date by multibeam bathymetry are shown in Figure A.14.

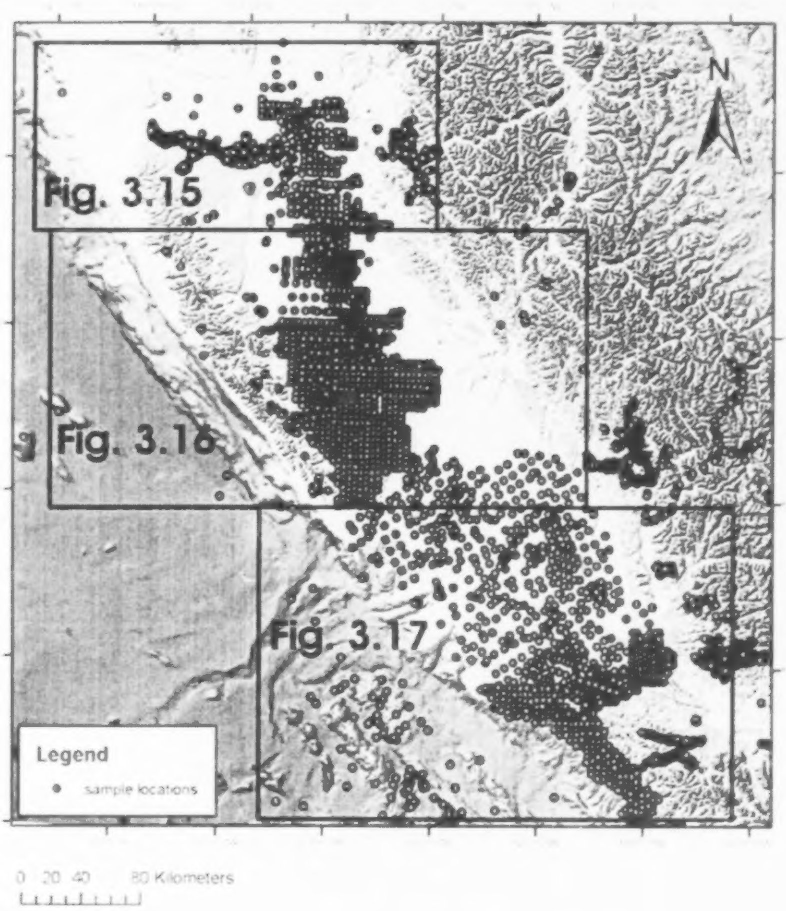

N
Fig. 3.15
Fig. 3.16
Fig. 3.17
Legend
● sample locations
0 20 40 80 Kilometers

Figure A.13 Distribution of GSC (Geological Survey of Canada) collected core and grab samples in the PNCIMA region. Inset boxes show locations of Figures A.15-A.17.

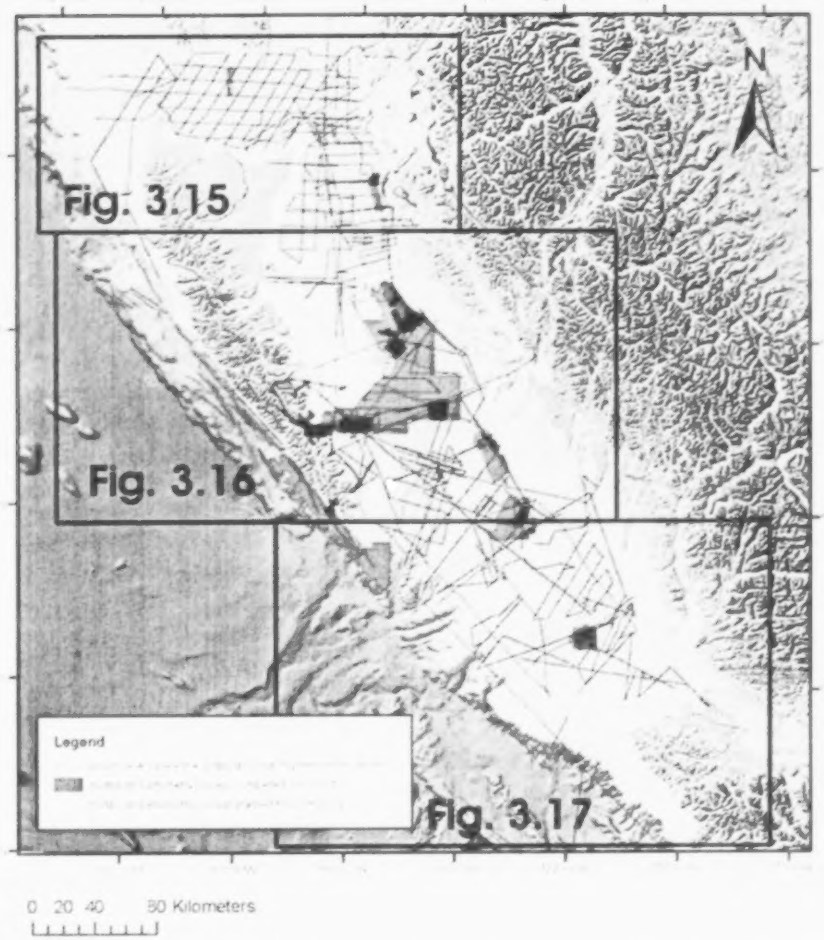

N
Fig. 3.15
Fig. 3.16
Fig. 3.17
Legend
0 20 40 80 Kilometers

Figure A.14 Location of geophysical tracklines collected by GSC and multibeam datasets acquired by CHS (Canadian Hydrographic Service) in PNCIMA. Inset boxes show location of Figures A.15-A.17.

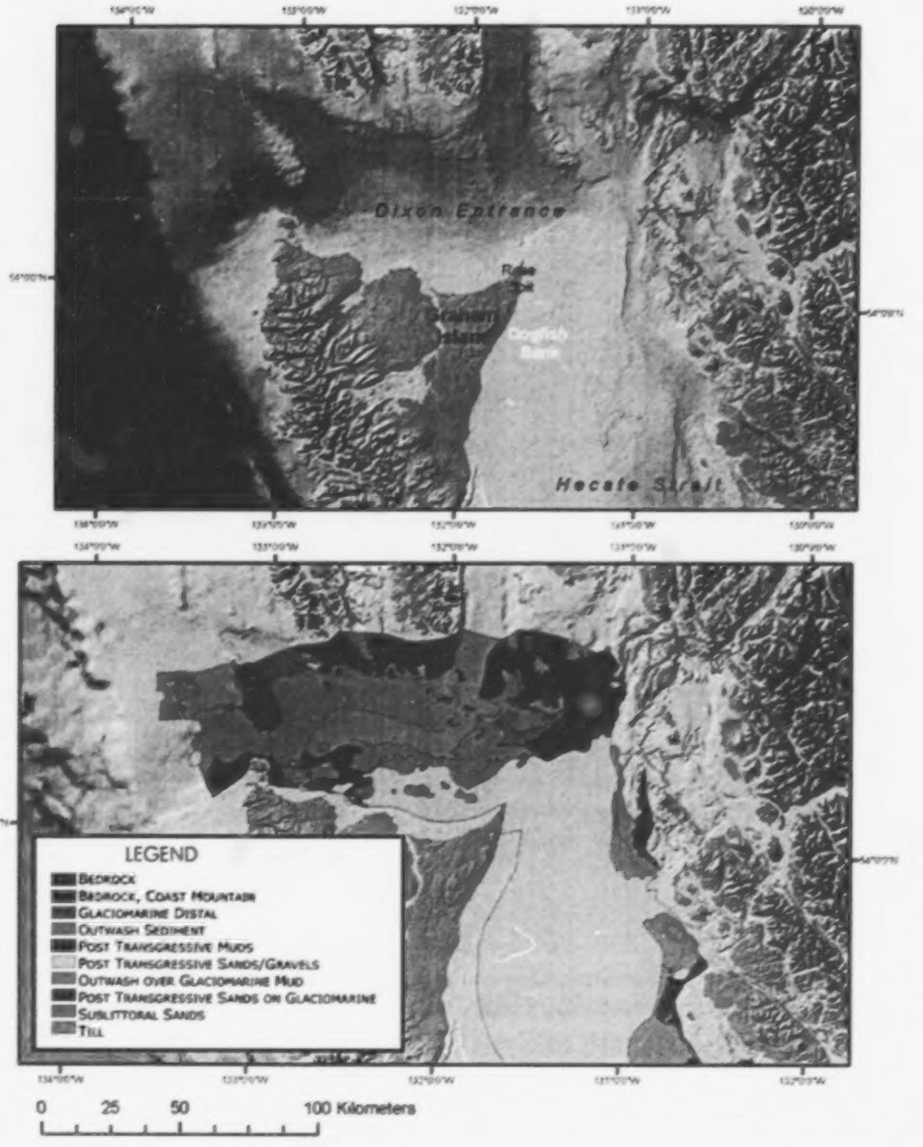

Dixon Entrance
Rose Spit
Graham Island
Dogfish Bank
Hecate Strait
LEGEND
BEDROCK
BEDROCK, COAST MOUNTAIN
GLACIOMARINE DISTAL
OUTWASH SEDIMENT
POST TRANSGRESSIVE MUDS
POST TRANSGRESSIVE SANDS/GRAVELS
OUTWASH OVER GLACIOMARINE MUD
POST TRANSGRESSIVE SANDS ON GLACIOMARINE
SUBLITTORAL SANDS
TILL
0
25
50
100 Kilometers

Figure A.15 Seafloor morphology (above) and geology (below) of the Dixon Entrance and northern Hecate Strait (after Barrie and Conway 1999).

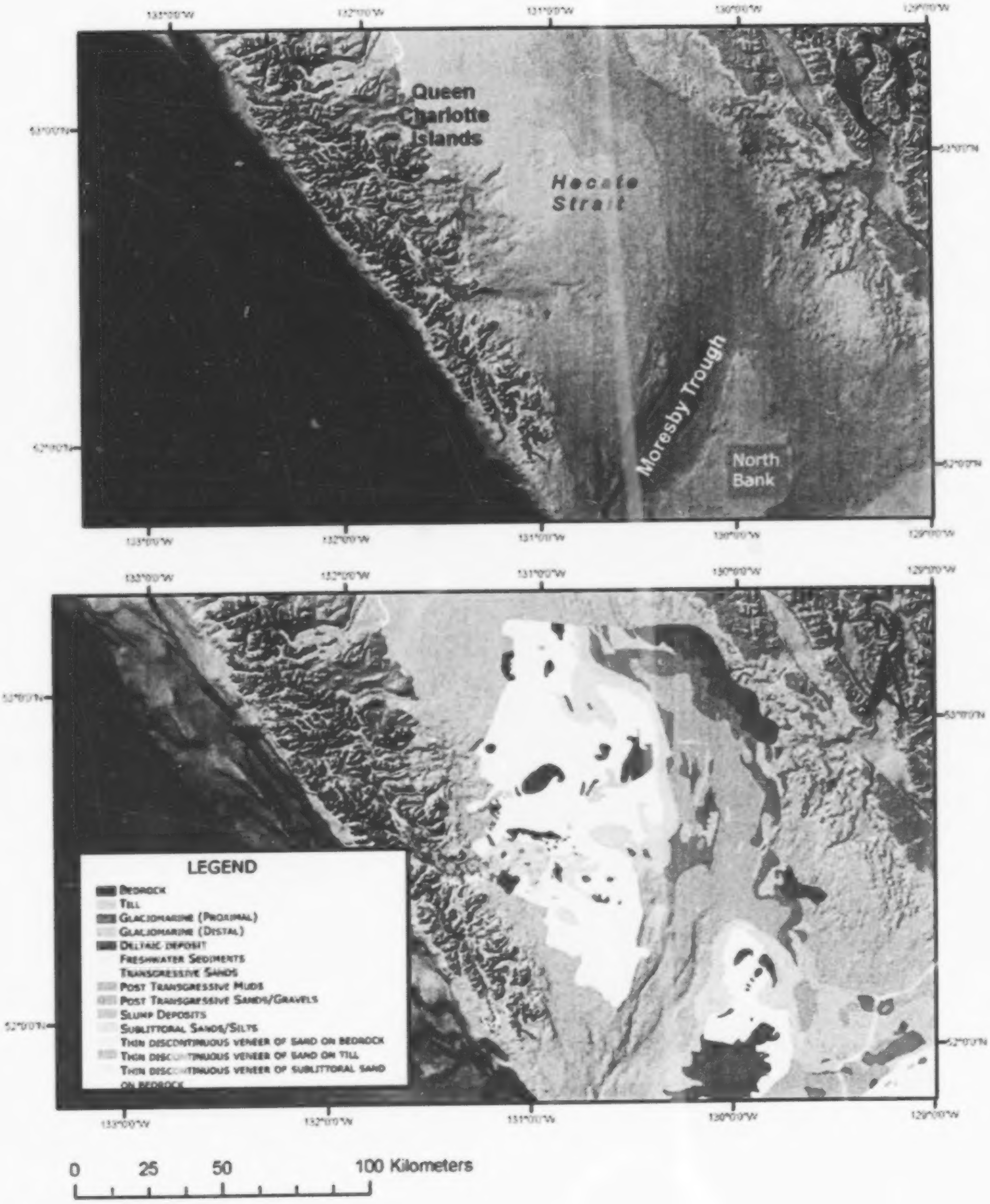

133°0'0"W
132°0'0"W
131°0'0"W
130°0'0"W
129°0'0"W
53°0'0"N
52°0'0"N
Queen Charlotte Islands
Hecate Strait
Moresby Trough
North Bank
LEGEND
Bedrock
Till
Glaciomarine (Proximal)
Glaciomarine (Distal)
Deltaic deposit
Freshwater Sediments
Transgressive Sands
Post Transgressive Muds
Post Transgressive Sands/Gravels
Slump Deposits
Sublittoral Sands/Silts
Thin discontinuous veneer of sand on bedrock
Thin discontinuous veneer of sand on till
Thin discontinuous veneer of sublittoral sand on bedrock
0
25
50
100 Kilometers

Figure A.16 Seafloor morphology (above) and geology (below) in Hecate Strait (after Josenhans 2006a).

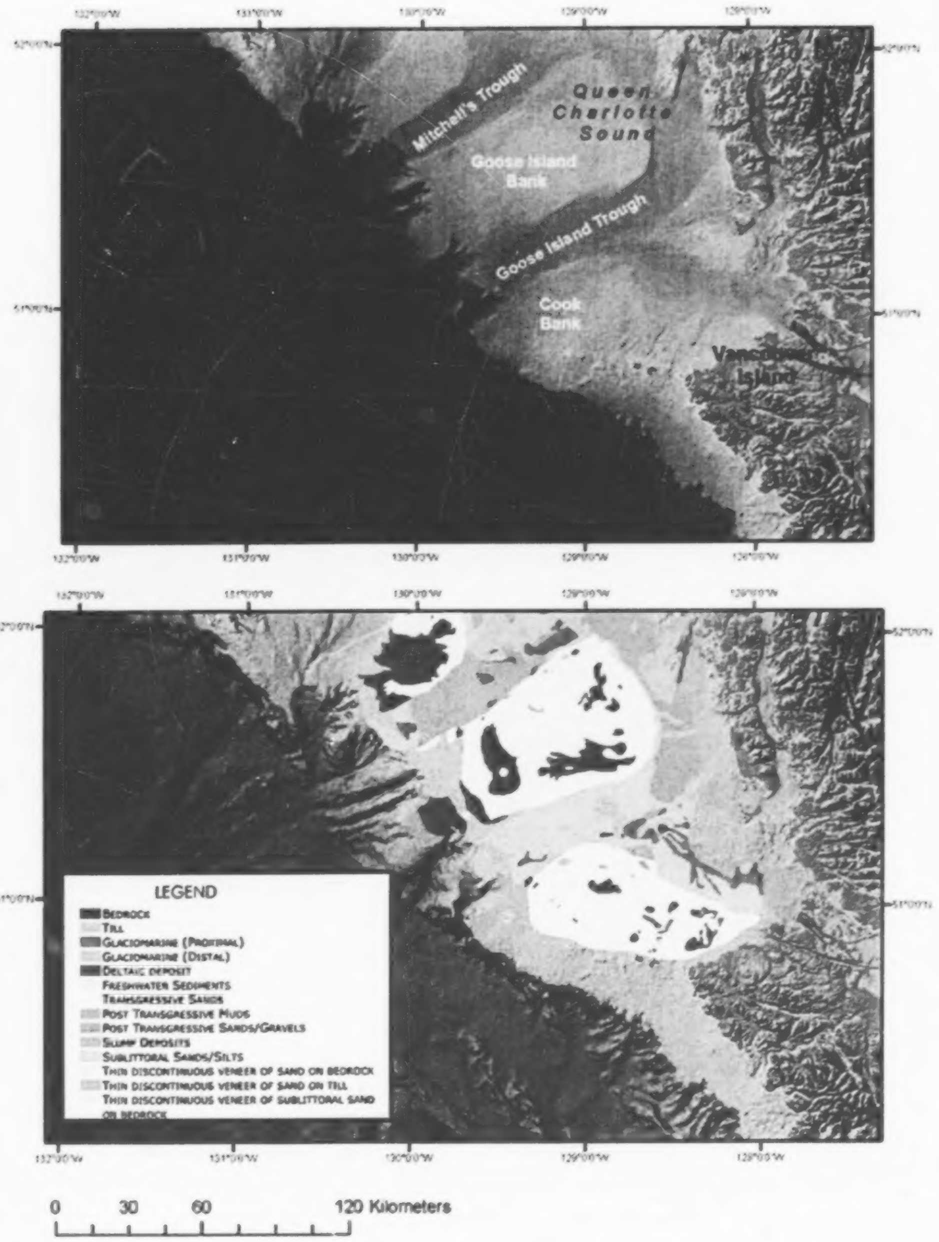
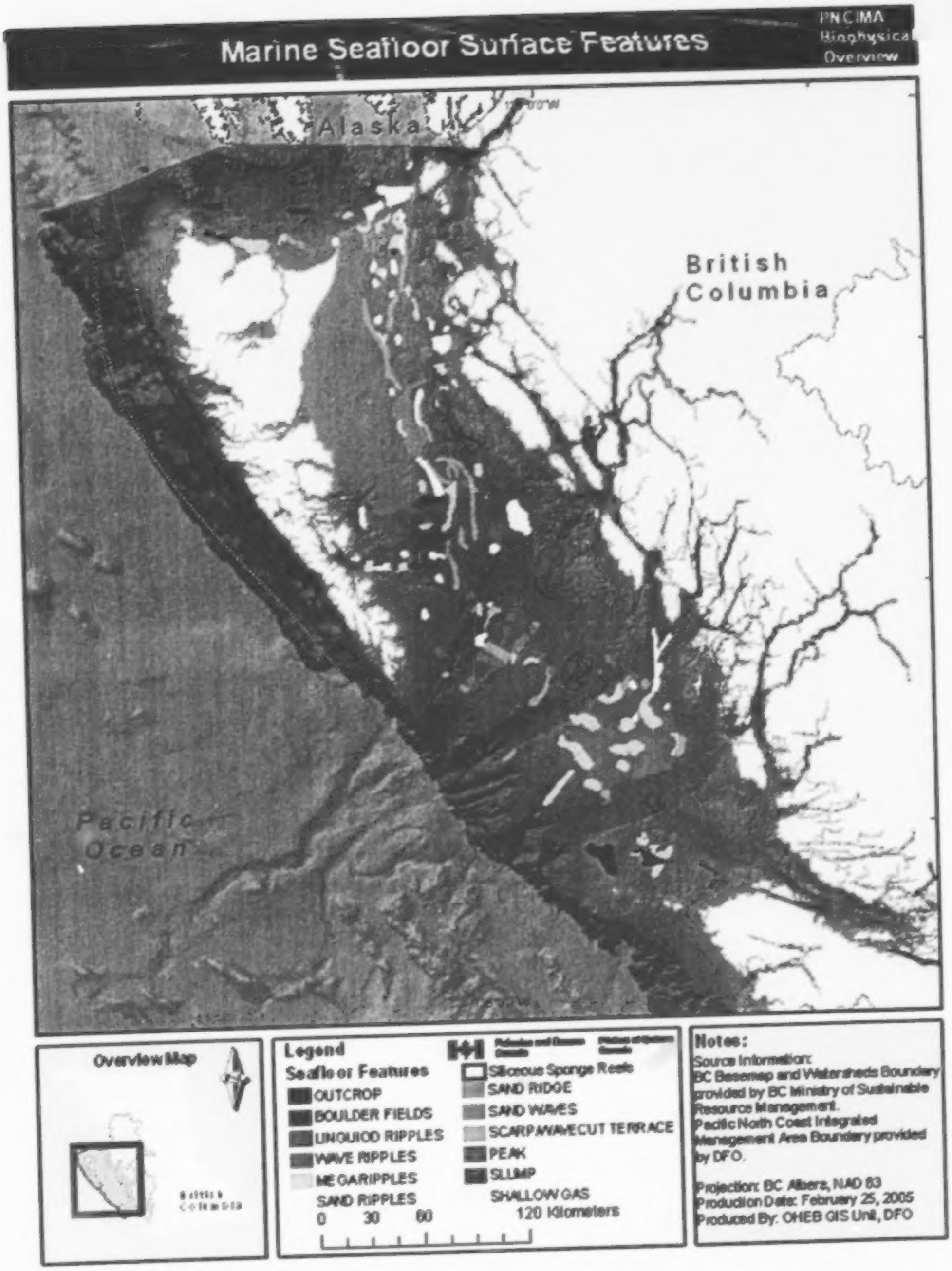

132°00'W
131°00'W
130°00'W
129°00'W
128°00'W
52°00'N
51°00'N
Mitchell's Trough
Queen Charlotte Sound
Goose Island Bank
Goose Island Trough
Cook Bank
Vancouver Island
LEGEND
Bedrock
Till
Glaciomarine (Proximal)
Glaciomarine (Distal)
Deltaic deposit
Freshwater Sediments
Transgressive Sands
Post Transgressive Muds
Post Transgressive Sands/Gravels
Slump Deposits
Sublittoral Sands/Silts
Thin discontinuous veneer of sand on bedrock
Thin discontinuous veneer of sand on till
Thin discontinuous veneer of sublittoral sand on bedrock
0
30
60
120 Kilometers

Figure A.17 Seafloor morphology (above) and geology (below) in Queen Charlotte Sound (after Josenhans 2006b).


Marine Seafloor Surface Features
PNCIMA
Biophysical
Overview
Alaska
British
Columbia
Pacific
Ocean
Overview Map
British
Columbia
Legend
Seafloor Features
OUTCROP
BOULDER FIELDS
LINGUIOD RIPPLES
WAVE RIPPLES
MEGARIPPLES
SAND RIPPLES
Siliceous Sponge Reefs
SAND RIDGE
SAND WAVES
SCARP/WAVECUT TERRACE
PEAK
SLUMP
SHALLOW GAS
0
30
60
120 Kilometers

Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.

Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.18 Known surficial seafloor features in PNCIMA (data from Natural Resources Canada 2005).

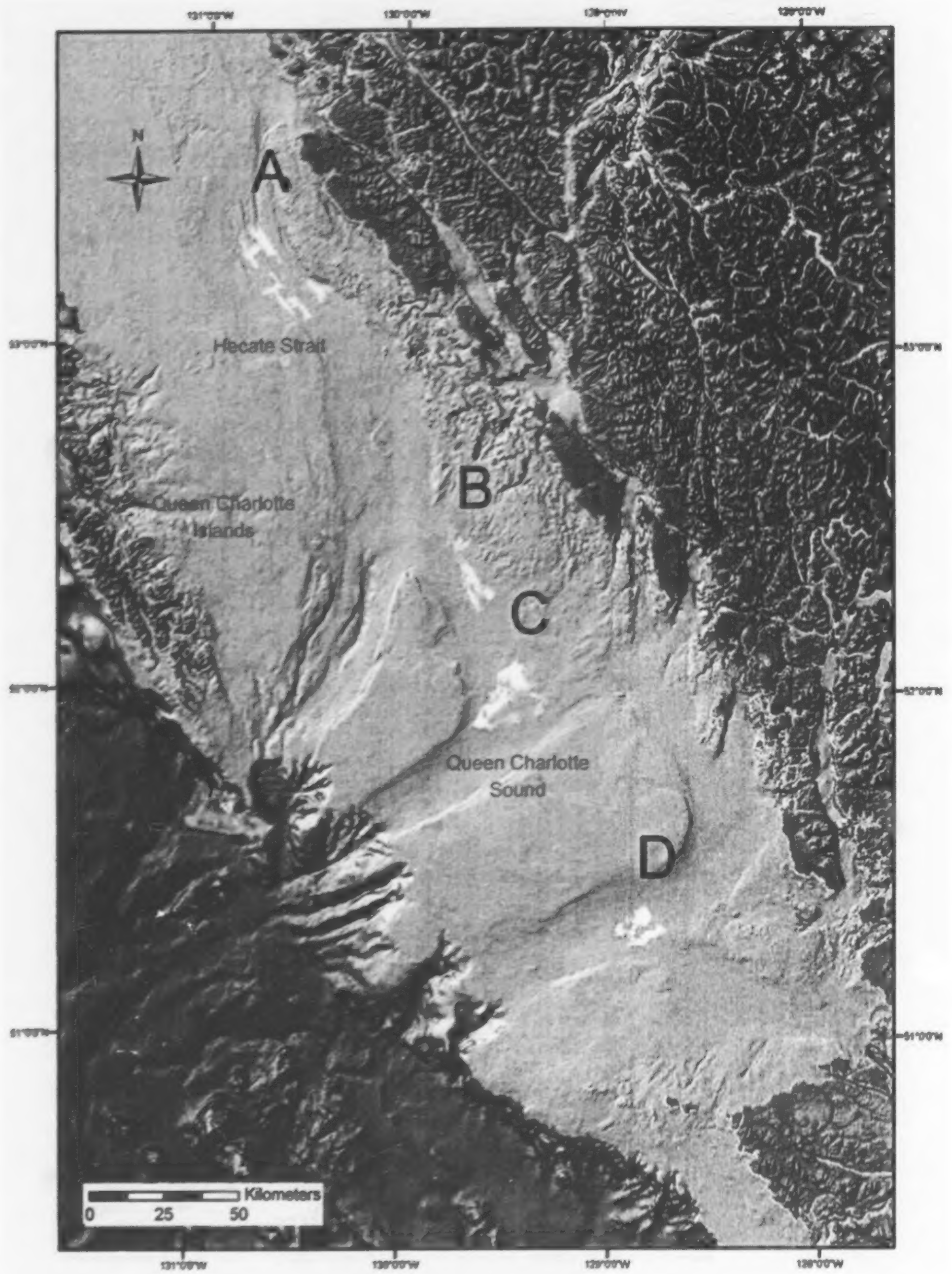

131°0'0"W
130°0'0"W
129°0'0"W
128°0'0"W
N
A
Hecate Strait
53°0'0"N
B
Queen Charlotte
Islands
C
52°0'0"N
Queen Charlotte
Sound
D
51°0'0"N
Kilometers
0
25
50

Figure A.19 Distribution of hexactinellid sponge reefs in the Queen Charlotte Basin. Letters refer to the various reef complexes.

4.0 SEDIMENTOLOGY

4.1 Marine Geology and Sediments

The Geological Survey of Canada (GSC) has conducted most of the research on the marine geology of the continental shelf of BC. Extensive sediment sampling has been accomplished by the GSC over many years. These core and grab samples locations are shown in Figure A.13. An extensive network of geophysical survey lines has also been collected and compiled over the last 25 years by the GSC and these data form the basis for a regional understanding of the geology of the PNCIMA region (Figure A.14). Recently compiled geological maps (Josenhans 2006a; 2006b) of PNCIMA (Figures A.15-A.17) show a clear trend for fine grained sediments to be found in the deep troughs and coarser grained sands, gravels, or bare bedrock to be found on the steep slopes and shallow tops of the banks.

Starting in 2002, sophisticated multibeam sonar technology has been applied to PNCIMA region (see section 1.4), and consequently our detailed knowledge of seafloor features, geohazards and sediment characteristics is advancing rapidly. Multibeam coverage to date is shown in Figure A.13. The multibeam program is an ongoing joint project of the GSC and the Canadian Hydrographic Service. Magnetic and subbottom profile data (3.5 kHz) are being collected simultaneously during these surveys. Previous work from the 1980s and 1990s has been summarized (Luternauer and Murray 1983; Barrie *et al.* 1991a; Bornhold and Barrie 1991) and maps of the area have been published (Barrie *et al.* 1990a; 1990b; 1990c).

The distribution of surficial sediments has been controlled by several factors, including; the effects of repeated Quaternary glaciations, sea level changes which accompanied the most recent glaciation, the present day wave and current regime that controls sediment transport, and the isolation of much of the shelf from a significant sediment supply. The Queen Charlotte Sound and Hecate Strait continental shelf is characterized by shallow banks and deep troughs (Figures A.15-A.17) that were excavated by successive glaciations (section 1.0). The most recent glaciation deposited sediments by a variety of glacial-marine processes following a sequence of ice proximal, coarse sediments through ice distal, fine sedimentation (Barrie and Conway 2002). These processes result in troughs that are floored by relatively thin recent muds that sit on up to 100 m of glacial sediments (Barrie *et al.* 1991a; 1991b). As glaciers receded to the mainland as an iceberg calving ice-front (Barrie and Conway 2002), meltwaters re-worked these sediments in shallow waters and a simultaneous local drop in sea level (Luternauer *et al.* 1989a) exposed the banks to littoral processes so that surficial sediments in these areas were remobilized to form large coastal features such as wave-cut scarps and terraces (Barrie 1988), spits and beaches (Josenhans *et al.* 1995), and deltas (Barrie and Conway 2002). In addition, in the troughs, icebergs scoured the seabed in deeper-water areas during the same time interval, creating the habitat upon which sponge reefs would subsequently develop. These unique reefs are restricted to such glacial substrates (Conway *et al.* 1991; 2005a).

In recent (Holocene) times, hydrodynamic energy has remained high on most of the continental shelf given the exposure of most of the region to Pacific Ocean swell and an intense tidal regime (Barrie *et al.* 1988; Crawford 2001). This particularly affects the shallow banks which continue to be covered in mobile sand and gravel deposits. With the establishment of Holocene sea levels, much of the recent sediments derived from the continental landmass are trapped in the fjords and channels bordering the mainland that act as settling basins (Luternauer and Murray 1983), so that much of the continental shelf receives no appreciable new sediments from mainland sources, but is sediment starved. The preponderance of rocky shorelines on the BC coast and the relatively thin layer of modern muds found in the deeper troughs and basins of the continental shelf are indicative of this paucity of sediments. This relict, sediment starved condition has also contributed to the development of the extensive sponge reefs in the shelf troughs that are founded to a large extent on exposed 15,000 year old iceberg furrows. The limited sediment input may be a critical factor in the development of hexactinellid sponge reefs described above, which could be subject to smothering by too much sediment input (Conway *et al.* 1991). More recent work suggests that some sponge populations, such as those found off the Fraser River, may be able to tolerate relatively high suspended sediment concentrations (Conway *et al.* 2004).

The Dogfish Banks area of Hecate Strait is an area that is unique on the BC shelf for several reasons. It is an actively eroding coastline on the east side of Graham Island, and the shallow nearshore seabed of the bank (Figure A.15) is regularly reworked by intense southeast storms. The nearshore, the intertidal zone and the shoreline are a dynamic system where up to 12 m of coastal erosion has been measured in one year (Barrie and Conway 2002). Rose Spit, the northeast point of Graham Island, is a constructional feature that has been growing for several millennia at least, as the eastern Graham shoreline erodes (Barrie and Conway 1996a), while the northern side of Graham Island has been growing for the past 5,000 years through onshore transport from Dixon Entrance and the accumulation of sediment in wide beaches and a dune system (Harper 1980). It has been suggested that localized tectonism may play a role in these sediment transport phenomena (Harper 1980; Barrie and Conway 1996b), though vertical tectonic movements are thought to be at least an order of magnitude lower than isostatic movements shortly after deglaciation (Barrie and Conway 2002, and references therein). Sediment dynamics on this vulnerable, unconsolidated coastline are thus quite different than most of the PNCIMA region that is dominated by rocky indented shores, and sparse nearshore and coastal sediments.

Although relatively little bathymetric surveying has been done in Dixon Entrance, compared to the rest of PNCIMA, it has been determined that the seafloor is underlain by thick glacial deposits (Figure A.15) (Barrie and Conway 1999). The glacial sediments are overlain by a thick layer of reworked muddy sand (transgressive sand) that remains the dominant exposed sediment, suggesting that energy levels have remained high since the end of glaciation. Although in shape it resembles one large trough, Dixon Entrance is broken into basins by three cross-cutting volcanic sills (Barrie and Conway 1999).

Recent work by DFO and GSC scientists on the relationship between groundfish species and substrate type appears to indicate that certain species show a preference for coarse sands and gravels, while others seem to prefer finer grained substrates such as sandy silts or muds. This is indicated in the species composition of trawl catches over the banks vs. within the troughs (A. Sinclair, DFO, Pacific Biological Station, Nanaimo BC. pers. comm., 2003). This interpretation is complicated by the tendency for certain species to prefer certain depths while substrate types are also segregated by depth (Sinclair *et al.* 2005).

Linkages between the regional physical and chemical oceanography and sponge reef development have recently been examined. These results indicate that the siliceous sponge reefs exist in a silicate rich environment that is enriched by wind-driven downwelling of productive surface waters (Whitney *et al.* 2005), and that tidally modulated transport of fine particles on the shelf and bathymetrically focussed delivery of nutrients and sediments enhances the growth of the sponge reefs. The canyon setting of the main reef complexes (Figures A.18 and A.19) acts to funnel nutrients and sediments to reef sites (Conway *et al.* 2005b). The "sediment" particles captured at the reefs have a large proportion of biogenic component of diatoms and foraminifera, accounting for up to 30 % of the reef sediments as measured in core traps (Conway *et al.* 2001) and up to 70 % as measured in sediment traps (Geological Survey of Canada - Pacific unpublished data). This suggests direct linkages between the surface water processes of primary productivity (photosynthesis) to the benthic ecosystem and sponge reefs.

4.2 Terrestrial Soils and Sediments

Soil information in Canada exists at both fine and coarse scales. The National Soils Data Base contains data from detailed soil surveys across Canada, but these fine scale surveys target agricultural areas, so coverage of PNCIMA is almost non-existent. However, at a coarser scale, the Canadian Soil Information System has used regional information to produce the Soil Landscapes of Canada which are mapped as polygons at a 1:1 million scale.

PNCIMA watersheds are dominated by the bare rock and ice of the higher elevations of the Coast Mountains. Aside from that, low organic content soils dominate with a few areas of organic soil in low-lying coastal regions. The soil development dataset (Figure A.20) classifies the dominant soil in the polygon according to the Canadian System of Soil Classification (Soil Classification Working Group 1998). PNCIMA watersheds are almost entirely covered by only three soil types; two kinds of Podzols and an Organic soil. Descriptions of these three soils are summarized below from the 3rd edition of the Canadian System of Soil Classification (Soil Classification Working Group 1998).

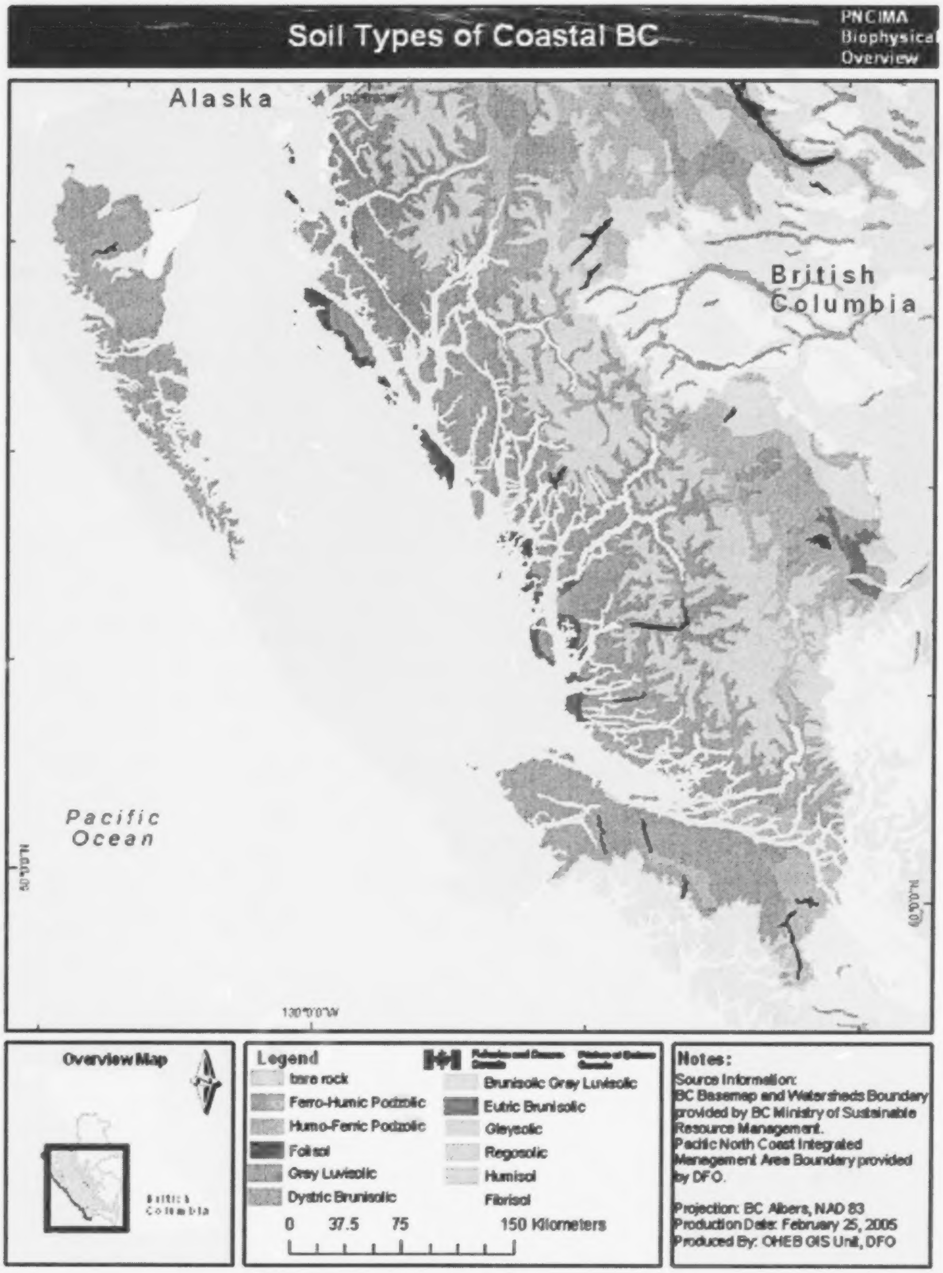

Soil Types of Coastal BC
PNCIMA
Biophysical
Overview
Alaska
British Columbia
Pacific Ocean
50°0'0"N
60°0'0"N
130°0'0"W
Overview Map
British Columbia
Legend
bare rock
Ferro-Humic Podzolic
Humo-Ferric Podzolic
Folisol
Grey Luvisolic
Dystric Brunisolic
Brunisolic Grey Luvisolic
Eutric Brunisolic
Gleysolic
Regosolic
Humisol
Fibrisol
0
37.5
75
150 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.20 Map of soil development types. Data from the National Soils Data Base, (see Agriculture and Agri-Food Canada 2005 for full soil type descriptions).

The National Soils Data Base contains further detailed information about soils and soil chemistry as well as the addition of climate data. This allows for a greater range of possible uses and analyses. For example, the terrestrial Biogeoclimatic Zones of BC (Meidinger and Pojar *eds*. 1991), are a form of ecosystem definition based on a combination of vegetation, soil, and climate (which indirectly includes elevation and latitude).

5.0 RESOURCE POTENTIAL

5.1 Offshore Oil and Gas

This topic is dealt with in further detail in the PNCIMA Marine Use Analysis (Fisheries and Oceans Canada 2007). For the completeness of this chapter a short summary is provided here.

On Canada's Pacific margin there are four relatively large sedimentary basins that could potentially contain petroleum (Figure A.21). These basins are geologically young (Georgia <100 Ma (million years ago), Tofino < 60 Ma, Queen Charlotte < 30 Ma, Winona < 6 Ma) (Hannigan *et al.* 2001). Three of the basins are part of the Pacific continental shelf (Queen Charlotte, Tofino, and Georgia) and these basins have been partially explored. The Winona basin is relatively unexplored and lies at the base of the continental slope in deep water.

Median in-place estimates of petroleum potential in these basins given in Table A.0 are based on complex analyses of the basins, but no significant oil or gas has yet been discovered. The Geological Survey of Canada has published work on the geology and hydrocarbon potential of the basins, most notably Woodsworth (1991) and Hannigan *et al.* (2001; 2005). All of these reports agree that the largest and most prospective basin is the Queen Charlotte Basin.

Table A.0 Median in-place estimates of the petroleum potential in the four west coast basins (data summarized in Hannigan *et al.* 2001).

Resource Type	**Georgia Basin**	**Tofino Basin**	**Queen Charlotte Basin**	**Winona Basin**
Oil	No estimate provided	No estimate provided	1.56 billion m^3 (9.8 billion barrels)	No estimate provided
Gas	185 billion m^3 (6.5 trillion ft^3)	266 billion m^3 (9.4 trillion ft^3)	734 billion m^3 (25.9 trillion ft^3)	

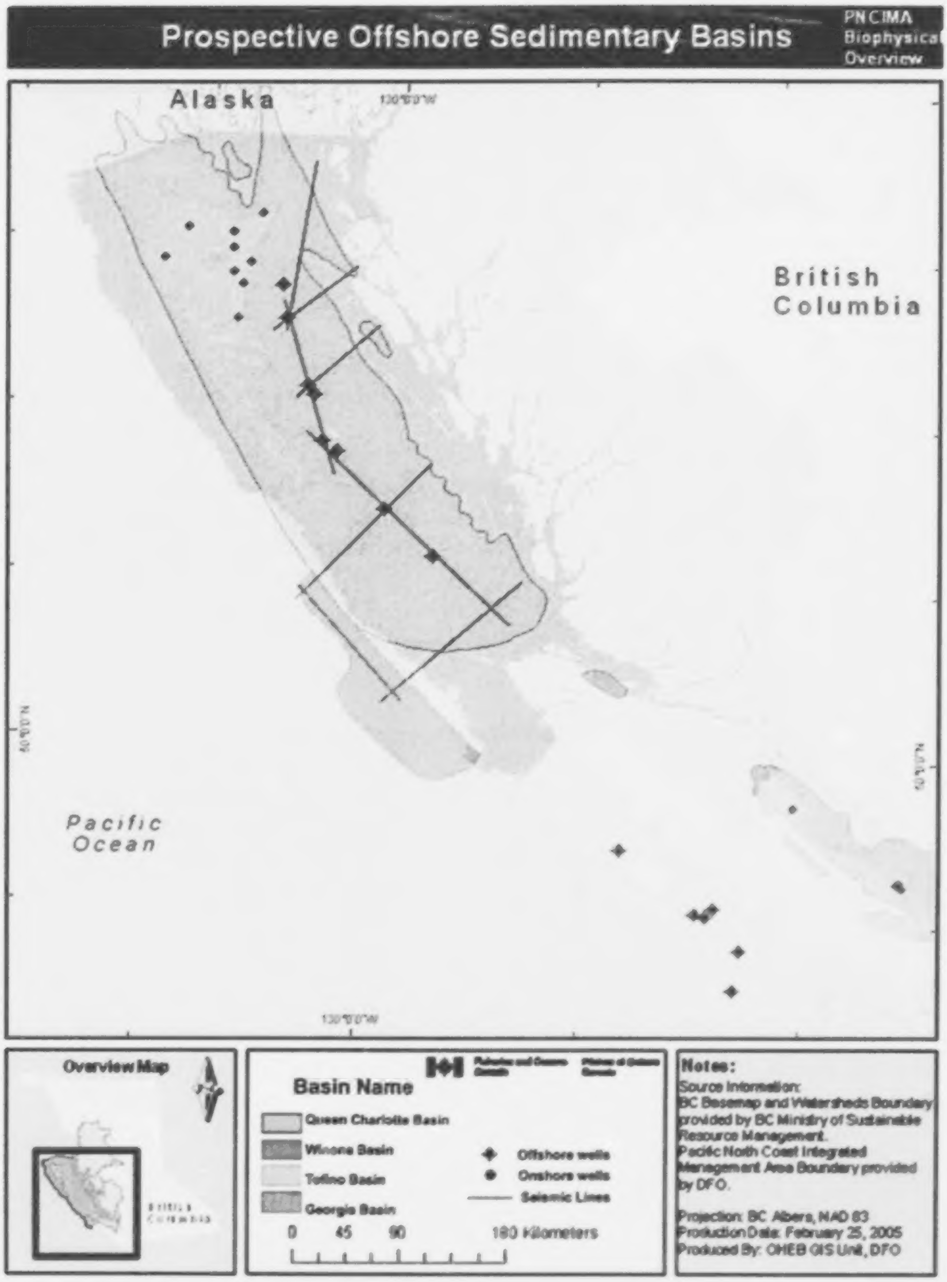

Prospective Offshore Sedimentary Basins
PNCIMA Biophysical Overview
Alaska
130°0'0"W
British Columbia
Pacific Ocean
50°0'0"N
50°0'0"N
130°0'0"W
Overview Map
Basin Name
Queen Charlotte Basin
Winona Basin
Tofino Basin
Georgia Basin
Offshore wells
Onshore wells
Seismic Lines
0 45 90 180 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure A.21 The four major sedimentary basins on the Pacific Margin of Canada with the location of past exploratory onshore and offshore drill wells and multichannel seismic lines shot by the GSC in 1988 (data from BC Ministry of Energy and Mines). Not shown is industry seismic data collected in the 1960s and 1970s.

There are actually two basins in the Queen Charlottes region (Hannigan *et al.* 2005), the older and less significant Hecate Basin, which is Cretaceous in age, and the younger, Tertiary age, Queen Charlotte Basin (QCB). The QCB is an upper Tertiary strike-slip basin that developed in response to transtensional and transpressional Pacific-North America plate interactions (Lewis *et al.* 1991; Rohr and Dietrich 1992; Rohr and Currie 1997). The basin encompasses some 40,000 km^2 and is underlain by Mesozoic and lower Tertiary volcanic, plutonic and sedimentary rocks. QCB basin-fill sediments were derived from variable source areas and directions. In detail, the basin consists of a series of separate or partly coalesced strike-slip sub-basins, which developed across a 150 km-wide, plate margin parallel shear zone (Rohr and Dietrich 1992; Dietrich 1995). The subbasins are commonly half grabens bound by normal or oblique slip faults. Overlying the sediments that infilled the lower part of the basin as it was being faulted (syn-rift sediments) are relatively undeformed clastic sediments that are more laterally continuous and which drape the deeper structures. The complex tectonic history of the region has formed many structures within the basin that could act as petroleum traps. Although no oil or gas pools have yet been discovered, indications of oil have been encountered in exploratory wells, and oil, tar, or gas seeps have been found on the Queen Charlotte Islands (Hamilton and Cameron 1989) and offshore (Barrie 1988).

5.2 Exploration History

Richfield Oil Corporation first began activity in the Queen Charlotte region in 1958 with an onshore drilling program of five wells on Graham Island, followed by marine seismic surveys in Hecate Strait. Between 1963 and 1967, Shell Canada conducted offshore seismic surveys and geological mapping. The results provided the impetus for a drilling program between 1967 and 1969, which resulted in fourteen wells being drilled. Minor shows of oil and gas were encountered in four of the eight wells drilled in the Queen Charlotte Basin (Figures A.21 and A.22).

The federal and provincial governments both imposed moratoria on oil and gas activities offshore BC in the early 1970s, initially related to concerns surrounding crude oil tanker traffic from the Alaskan oil fields to markets in the US, as well as to jurisdictional disputes between Canada and BC concerning the Strait of Georgia.

The moratoria have been reviewed a number of times during the last three decades and in the early 1980s various environmental evaluations and reviews were developed (Chevron Canada Resources Ltd. 1982; Planning and Assessment Branch (BC Ministry of Environment) 1983; Petro-Canada 1983; West Coast Offshore Exploration Environmental Assessment Panel 1986). A joint federal-provincial environmental assessment panel recommended in 1986 that exploration activity could take place subject to some 90 conditions (West Coast Offshore Exploration Environmental Assessment Panel 1986). In June 1987, federal and provincial governments issued a joint response to that panel report, accepting the intent of a majority of the recommendations and announced that exploration activities would proceed "in the near future" subject to the signing of an offshore management accord. However, in 1989, as a result of environmental concerns arising from oil tanker spills off BC and Alaska, and due to a lack of development interest by industry, the two governments decided to extend the moratoria indefinitely.

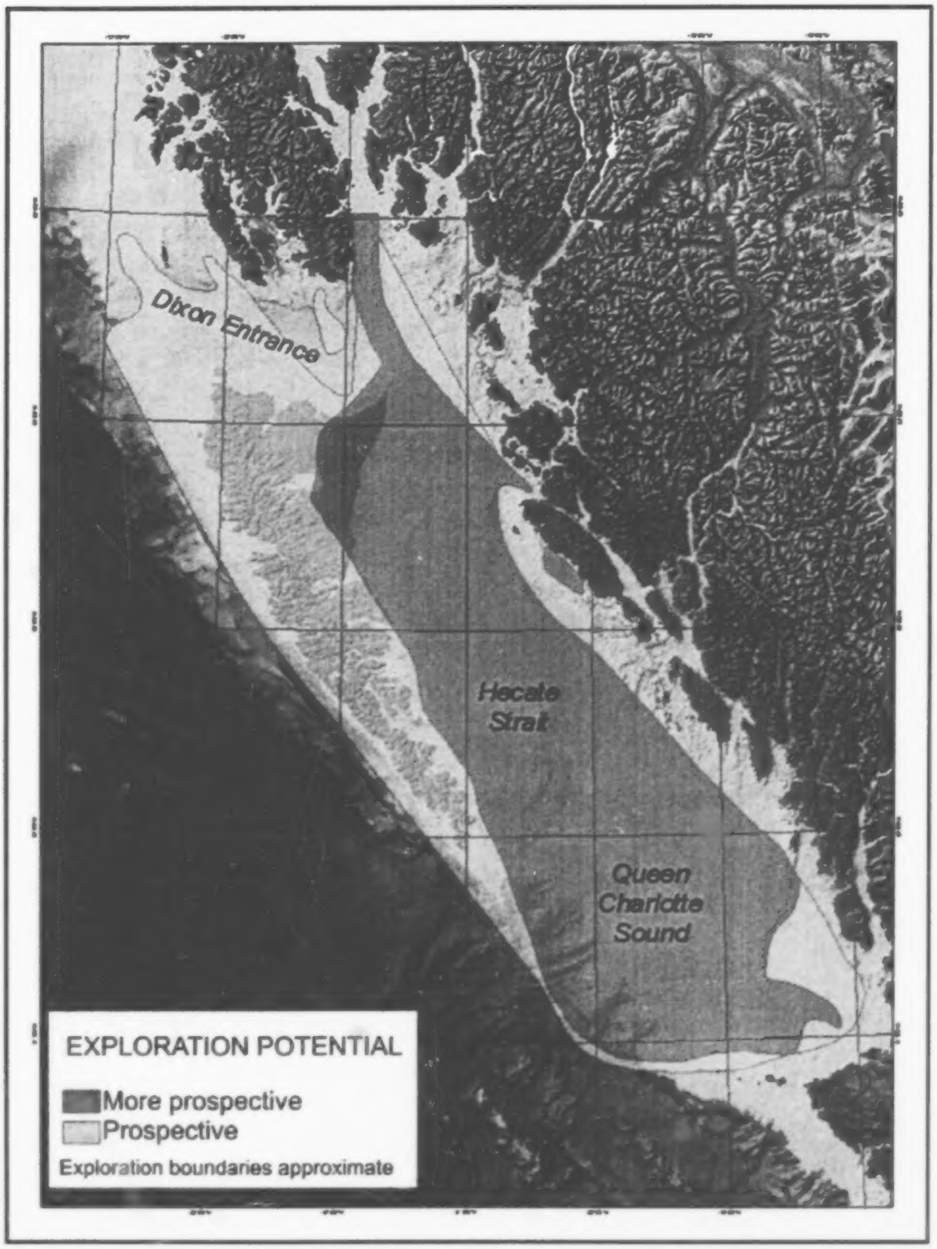

Dixon Entrance
Hecate Strait
Queen Charlotte Sound
EXPLORATION POTENTIAL
More prospective
Prospective
Exploration boundaries approximate

Figure A.22 Petroleum exploration potential in the Queen Charlotte Islands area.

In 2002, BC commissioned a scientific review of the moratorium and held stakeholder consultations. The conclusions indicated that there are no scientific or technical inadequacies that required a blanket continuation of the moratoria. After Cabinet consideration in December 2002, the Government of Canada initiated a three-part federal review process in March 2003 to identify any science gaps, and seek the views of the public and First Nations concerning whether or not to lift the moratorium for the Queen Charlotte Basin area. The Royal Society of Canada's independent science report prepared for Canada concluded in February 2004 that, provided an adequate regulatory regime is put in place, there are no science gaps that need to be filled before lifting the moratorium on oil and gas development (Hall *et al.* 2004). However, it noted that numerous science activities should be undertaken prior to exploration, development, and production activities.

Reviews of status of knowledge in the region related to offshore industrial development has been summarized in various reports in the last decade (Strong *et al.* 2002; Hall *et al.* 2004; Jacques Whitford Environment Ltd. 2001; Simon Fraser University 2000; Crawford *et al.* 2002; Jamieson and Davies 2004; Cretney *et al.* 2002a; 2002b; 2002c). A more detailed chronology of offshore oil and gas activity can be found on the BC Ministry of Energy and Mines web site, including more recent results (http://www.offshoreoilandgas.gov.bc.ca/).

5.3 Natural Gas Hydrates

Gas hydrates are ice-like substances (called clathrates) composed of molecules of natural gas trapped within the crystalline structure of frozen water. Methane hydrate is thought to be the most common in nature. They can form in areas of deep permafrost and such formations are found in the Canadian Arctic (Hyndman and Dallimore 2001). They can also form in ocean sediments where bottom temperatures are cold, depths are greater than 400 m, and there is a source of natural gas. In subduction zones, the sedimentary section is scraped off the subducting plate, creating an accretionary prism, and this is the case along the Vancouver Island margin. As the accretionary prism builds, porosity decreases rapidly with depth, causing methane rich pore fluid to be expelled and percolate upwards into the hydrate stability field, forming significant gas hydrate deposits (Hyndman and Davis 1992; Hyndman *et al.* 2001; Spence *et al.* 2000). Deposits may also exist further north, within the PNCIMA continental slope, but this has not been confirmed. The majority of the continental shelf is thought to be too shallow for gas hydrates to form.

Gas hydrates are significant for three reasons. First, natural gas is a fairly clean energy source and gas hydrates are thought to be very abundant worldwide. Furthermore, the clathrate structure is very efficient at storing the gas as one volume of gas hydrate will produce over 160 volumes of methane gas. Second, methane is a strong greenhouse gas and gas hydrates are a significant methane sink, so that the formation or melting/dissociation of gas hydrates have large climate implications. Third, the gas hydrates can be a seafloor hazard either due to shallow gas release or by contributing to seafloor instability (Hyndman and Dallimore 2001).

5.4 Offshore Aggregate Resources

More than 6.3 x 10^6 dry metric tonnes of sand and gravel aggregate has been mined from the nearshore waters of the basin near Prince Rupert since 1956 (Good 2004). This aggregate production was undertaken from some 17 Provincial lease blocks starting in 1956 and ending in 1997. The majority of the production was undertaken at one site where a tombolo near Metlakatla was completely removed. This production was largely unregulated and no environmental monitoring was undertaken. Construction aggregate is currently trucked in from the interior of the mainland, or obtained by small, local blasting and crushing operations. For any large-scale project within the basin, such as oil and gas production platforms, aggregate supplied by either of these options would be costly and logistically problematic, especially relative to barge transport of locally dredged material.

5.5 Marine Placer Mineral Deposits

Placers gold have been exploited in the intertidal and supralittoral zone on Graham Island for more than a century (Mandy 1934). In addition to coastal placers, shelf placer deposits of titanium rich sands are known to exist (Barrie *et al.* 1988). There is thus significant potential for marine placer resources to occur within the PNCIMA region.

5.6 Terrestrial Mineral Potential

A detailed review of the terrestrial mining activity in PNCIMA watersheds can be found in the PNCIMA Marine Use Analysis. Information on contaminant issues related to mining can be found in Haggarty *et al.* (2003).

6.0 ACKNOWLEDGEMENTS

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7.0 GLOSSARY

Accreted – The process of adding crustal blocks to continental land masses. Accreted terranes are those that become attached to a continent (e.g., western North America) as a result of tectonic processes.

Accretionary prism – Accretionary prisms grow at subduction zones, where sediments are scraped off, bulldozer-fashion, near the trench, or by underplating of subducted sediments and oceanic crust along the shallow parts of the subduction zone.

Clathrates – A clathrate or clathrate compound is a chemical substance consisting of a lattice of one type of molecule trapping and containing a second type of molecule. In the case of gas hydrate water molecules encloses a trapped gas molecule.

Eustatic – Pertaining to worldwide changes in sea level that affect all oceans, caused in the last few million years by the addition and removal of water from continental glaciers and ice caps.

Fluvial – Produced by the action of a stream or a river.

Grabens – An elongate relatively depressed crustal block that is bounded by faults on its long sides.

Isostatic – The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenoshere.

Lithology – The physical character of a rock.

Littoral – Pertaining to the depth zone between high water and low water.

Paleoseismic – Pertaining to earthquakes of the geologic past.

Piedmont lobe – A thick continuous ice mass at the base of a mountain range.

Refugia – An isolated area that underwent little environmental change permitting a fauna or flora to persist locally long after it had been exterminated elsewhere.

Subducted – The process of one lithospheric plate descending beneath another.

Terranes – A terrane is a crustal block or fragment that preserves a distinctive geologic history that is different from the surrounding areas and that is usually bounded by faults.

Tombolo – A sand or gravel bar that connects an island with the mainland or with another island.

Transpression(al) Crustal – Deformation in zones of oblique compression that combines the two elements of strike slip and compression.

Transtensional Crustal – Deformation in zones that combines the two elements of extension and strike slip motion.

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2007

ECOSYSTEM OVERVIEW:
PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX B: METEOROLOGY AND CLIMATE

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1.0 INTRODUCTION

British Colombia's coastal climate and weather conditions are a direct result of its position between the northeast Pacific Ocean and the Coast Mountains. Winds are dominated by the Aleutian Low in winter and the North Pacific high in summer. This means that winter storms absorb great amounts of moisture as they track eastward toward the British Columbia (BC) coast. Much of this moisture falls as precipitation when it hits the Coast Mountains, making BC's coast the wettest place in Canada. The positions of the air pressure systems often cause winter storms to hit the central and north coast of BC more frequently than the southern coast. This results in the highest rainfall totals occurring within the PNCIMA area.

The ocean also moderates temperatures, with the winter storm winds transporting heat across the central Pacific in winter and northwest summer winds bringing relatively cooler air masses onto the coast. These air pressure systems and their winds also drive ocean circulation, which controls the source, and thus temperature, of water off the BC coast.

Variations in climatic conditions strongly affect ecosystems. Most obvious is the seasonal variation that controls such things as the spring phytoplankton bloom, timing of peak stream flow, ocean wave intensity and ocean current strength. However, the variation between years and decades for a given season is of great significance as these conditions can strongly affect the timing of ecosystem functions, which can be critical to the success of various biota. El Niño events, for example, transport warm waters and their biological community northward to the BC coast, creating competition between indigenous and invasive organisms. There is an increasing focus in research on understanding how climate variability affects the ecosystem and whether that variability can be predicted.

1.1 Key Points

- The proximity of the Pacific Ocean moderates BC's coastal climate, producing relatively warm winters and cool summers compared to the interior of British Columbia. The position and strength of two large scale pressure systems over the northeast Pacific control much of the specific conditions of BC weather and climate. The Aleutian Low tends to dominate our winters. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC and Alaskan coasts. The North Pacific High dominates our summers and tends to deflect storms northward during this time. These pressure systems and their associated winds also drive the main ocean circulation patterns of the northeast Pacific (see Appendix C: Physical and Chemical Oceanography).
- The presence of the Coast Mountains produces very high rainfall on their coastal side (rainiest area in Canada), particularly along the north and central mainland

coast. Areas in the rain shadow of the coastal mountains receive significantly less rainfall.

- Climate variability is a critical factor in ecosystem function. It operates on a wide range of time scales, the most relevant of which are seasonal, interannual, interdecadal, and the climate change scale (10 to 100 yr).
- Warming of the earth's atmosphere and ocean (climate change) has been observed over the past century and is accelerating. This trend will have major effects on ecosystems.

1.2 Uncertainties, Limitations, and Variability

- Climate prediction on all time scales is difficult. Part of the problem is a lack of data gathered over and in the Pacific Ocean. The complexity of ocean-atmosphere systems and their interaction also prevents sufficient understanding for accurate predictions, although new observational programs are improving climate models through the collection of near real time oceanographic data. Thus, although it is known that climatic conditions are critical to ecosystem function, and that they vary significantly on various time scales, predictive capabilities need to be improved.
- Climate variability at various time scales is discussed in detail in section 4.0.

1.3 Major Sources of Information or Data

- The Meteorological Service of Canada (division of Environment Canada) collects and archives all meteorological information for Canada and provides weather forecasts and reports. They also conduct research on a variety of topics including climate, atmospheric science, and air quality. Victoria is the home of the Canadian Centre for Climate Modelling and Analysis (CCCma) of Environment Canada, which does significant work towards our understanding of climate variability and climate change.
- The Intergovernmental Panel on Climate Change (IPCC) has produced a number of reports relating to the evidence for, potential affects of, and possible reaction to climate change (http://www.ipcc.ch/). Reports on more local impacts and adaptations include work by the Canadian Climate Impacts and Adaptation Network (http://www.c-ciarn.ca/index_e.asp) as well as work by individual agencies (Fisheries and Oceans Canada *eds*. 2000; Bell *et al.* 2001; BC MWLAP 2002; Air & Waste Management Association 2003).
- An excellent summary of BC marine weather for the general reader is 'Living with the weather along the British Columbia coast: the veil of chaos' (Lange 2003).
- A detailed summary of BC climatology can be found in the World Survey of Climatology (Hare and Hay 1974). Brief summaries are found in a number of

broad topic reports (Scudder and Gessler *eds*. 1989; Ricker and McDonald 1992; Ricker and McDonald 1995; Hood and Zimmerman *eds*. 1986; Jacques Whitford Environment Limited 2001; Hall *et al.* 2004; Chevron Canada Resources Ltd. 1982; Petro-Canada 1983).

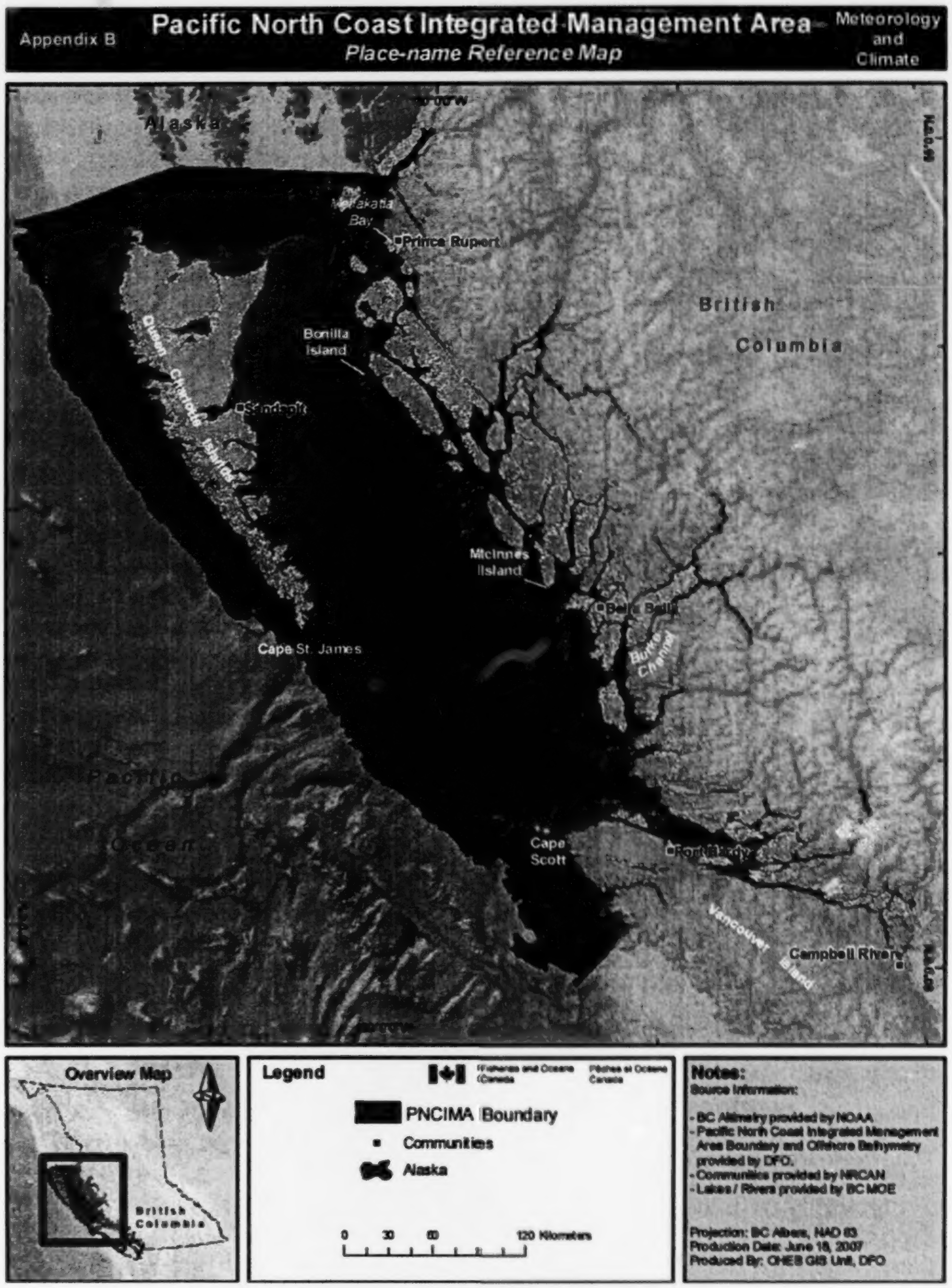
1.4 Identified Knowledge and Data Gaps

- Modelling of climate and coupled climate-ocean conditions is limited both by computing capacity (most of these efforts require supercomputers), and by a lack of monitoring data, especially over and within the Pacific Ocean. Advances in this area will improve climate prediction capabilities.
- A recent analysis was made of BC's climate observation capacity. The 'Review of the Adequacy of Climate Related Observation Networks' (M. Miles and Associates 2003), found that according to World Meteorological Organization standards, BC is severely lacking in climate and stream gauging, sediment discharge stations, and climate station density and is somewhat lacking in monitoring of evaporation, hydrometric networks and snow course density monitoring. Deficiencies are most common in areas that are remote, high elevation, or have small watersheds. This would describe most of the PNCIMA area. These deficiencies are specifically discussed in terms of the ability to verify and support climate modelling efforts.

2.0 WINDS AND PRESSURE SYSTEMS

The climate and weather conditions of the BC's coastal regions are largely governed by two Pacific Ocean air masses, as well as by the frequent west-to-east passage of cyclonic weather systems (most frequent from October through May), and the presence of large mountain belts parallel to the coast. It is one of the windiest areas of Canada: Cape St. James (at the southern end of the Queen Charlotte Islands, Figure B.0) holds the Canadian record for having the largest number of days each year (120 on average) with gale force winds. The strongest hourly winds measured in British Columbia (77 knots) were recorded at Bonilla Island on 20 February 1974 (Phillips 1990).

The two Pacific Ocean air masses are the Aleutian Low and the North Pacific High (Figure B.1). They not only influence the winds, air temperature, air moisture, and storm tracks in the region, but they drive the main surface currents of the North Pacific, which strongly control the sea surface temperature and other oceanographic conditions (described in Appendix C: Physical and Chemical Oceanography). These pressure systems vary seasonally (as described below) and they vary in intensity from year to year (Hamilton 1984), often making them the root cause of inter-annual fluctuations in the wind, forcing corresponding variations in the North Pacific wind-driven surface currents and associated climatic and oceanographic parameters.



Appendix B
Pacific North Coast Integrated Management Area
Place-name Reference Map
Meteorology and Climate
Alaska
Metlakatla Bay
Prince Rupert
Bonilla Island
British Columbia
Queen Charlotte Islands
Sandspit
McInnes Island
Bella Bella
Burke Channel
Cape St. James
Pacific Ocean
Cape Scott
Port Hardy
Vancouver Island
Campbell River
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Alaska
0
30
60
120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure B.0 PNCIMA region showing locations and features of BC waters.

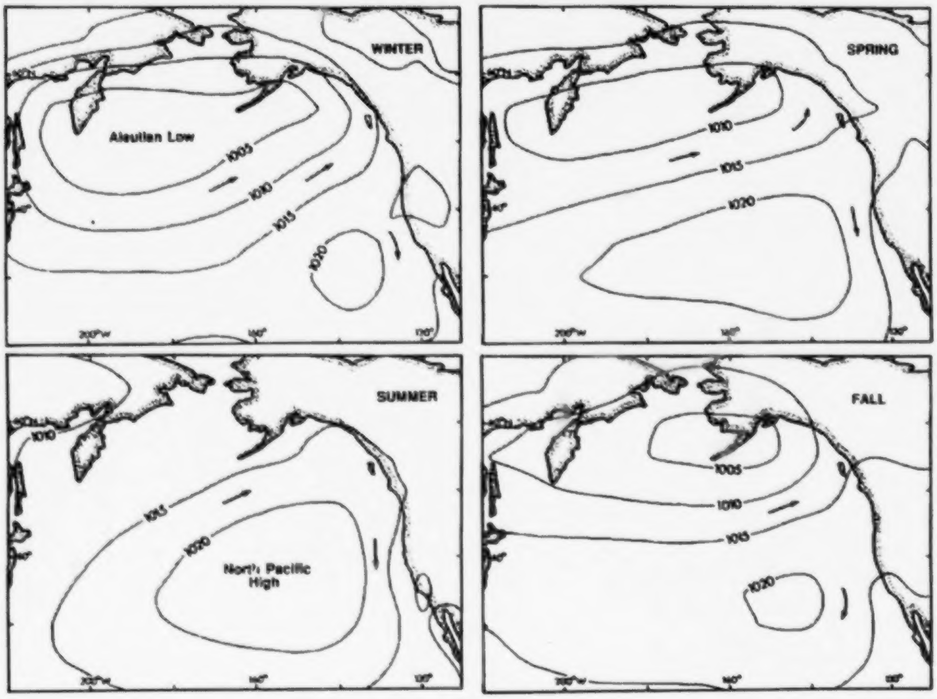


Figure B.1 Seasonal atmospheric pressure patterns (millibars), 1947-82 (from Thomson *et al.* 1989; Thomson 1989; Thomson and Tabata 1989, after Hamilton 1984).

During winter, a quasi-permanent low-pressure system, the Aleutian Low, dominates the North Pacific weather patterns (Figure B.1 top left). The average counter-clockwise flow around the Aleutian Low and the presence of the Coast Mountains results in mostly southeasterly winds along the BC coast. These extra-tropical cyclonic systems cross the North Pacific Ocean as two reasonably distinct storm tracks, one originating from the Kamchatka Peninsula of Russia and the other from southern Japan (Lambert 1988).

Raible *et al.* (2006) investigated the behaviour of the Aleutian Low in climate and proxy records as well as in global climate models. They found the intensification of this low from the year 1950 to 2000 was unlike its behaviour in the previous 500 years, and related this behaviour to climate warming.

Rapidly developing extra-tropical cyclones are more likely to impact the BC coast than other areas in Canada, with the exception of the Canadian Atlantic coast. These 'Coastal Low' weather systems are characterized by a rapid and sustained decrease in central air pressure and intensified wind speeds, and often by increased precipitation. These storms travel quickly and can be hazardous to marine operations. Winds up to 70 knots (gusts to 100 knots) are generated to the east and southeast of the Low. Over a typical winter, about 17 such storms develop and affect the British Columbia coastal area (Stewart *et al.* 1995). Gale force winds at Cape St. James are usually a precursor to the arrival of similar winds along the north and central mainland coast about 24 hours later. Figure B.2 shows a pressure pattern typical of a Coastal Low (Environment Canada 1992).

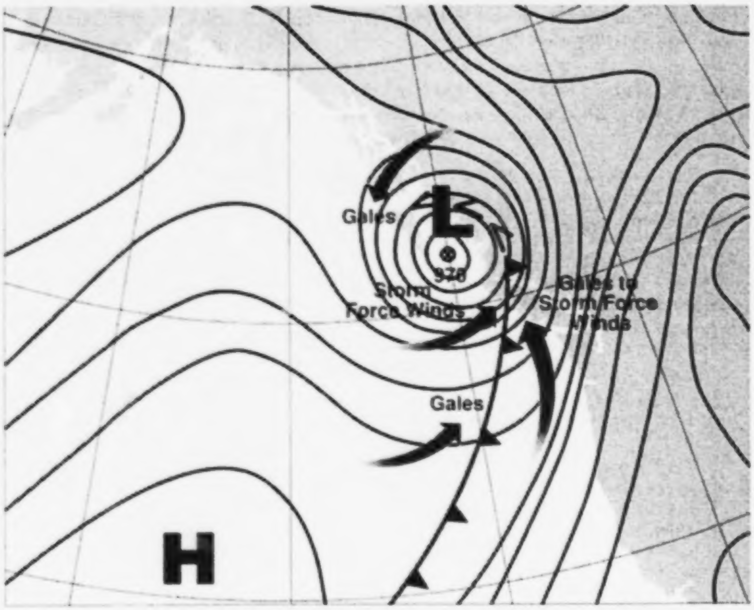


Figure B.2 Winter pressure pattern typical of a Coastal Low (millibars) (Environment Canada 1992).

In summer, the mean monthly weather patterns change with the North Pacific High moving northward and displacing the Aleutian Low (Figure B.1 bottom left). This pressure pattern tends to deflect most storms to the north as indicated by Figure B.3 (Environment Canada 1992). The clockwise airflow around this High results in weaker, mostly northwesterly winds along the central coast.

Summer wind speeds are much reduced from those of winter (Figures B.4 and B.5). However, strong marine winds can occur during late spring and summer, associated with the passage of frontal systems through the BC central and north coast. Even diurnal sea-breezes, caused by heating/cooling of the land, can be strong enough to disrupt vessel traffic during late afternoons.

In all seasons, wind intensity decreases towards the mainland coast.

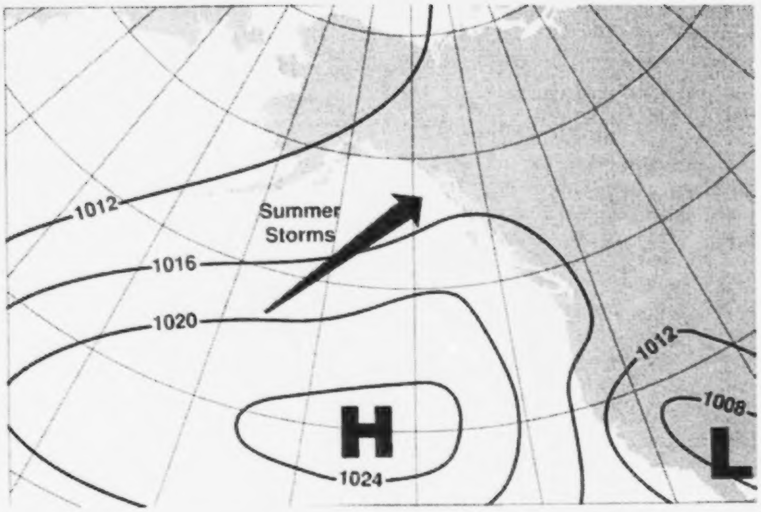

1012
Summer Storms
1016
1020
H
1024
1012
1008
L

Figure B.3 Summer pressure pattern (millibars) (Environment Canada 1992).

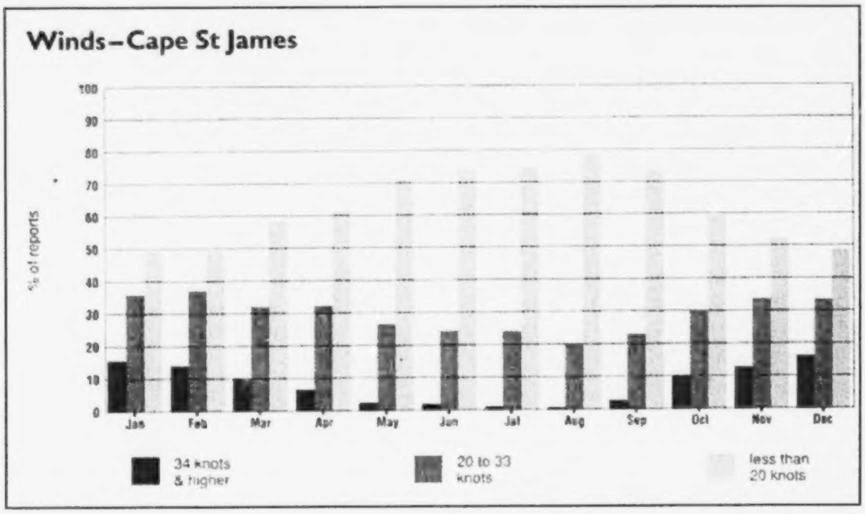


Figure B.4 The seasonal distribution of wind speeds for Cape St. James in the <20, 20-33, and >34 knot range (Environment Canada 1992).

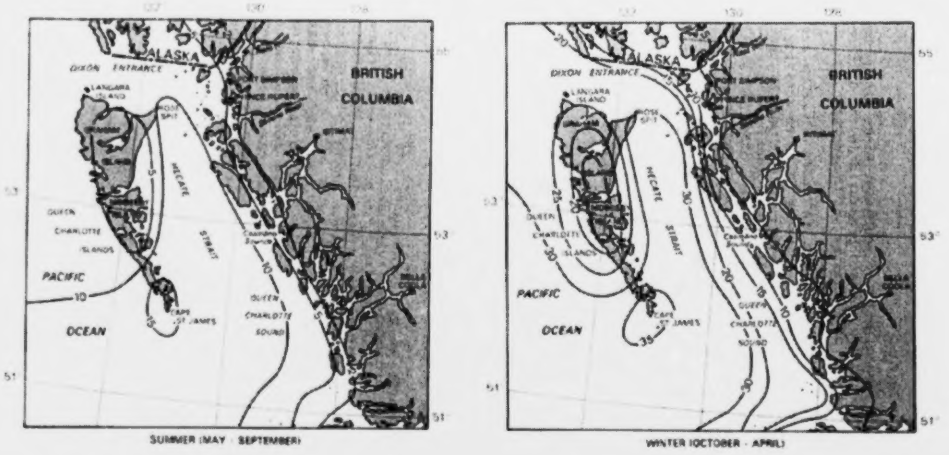

ALASKA
DIXON ENTRANCE
LANGARA ISLAND
ROSE SPIT
BRITISH COLUMBIA
HECATE STRAIT
QUEEN CHARLOTTE ISLANDS
PACIFIC OCEAN
CAPE ST JAMES
QUEEN CHARLOTTE SOUND
10
15
5
20
25
30
35
55
53
51
SUMMER (MAY - SEPTEMBER)
WINTER (OCTOBER - APRIL)

Figure B.5 Percent frequency of winds ≥40 km hr^{-1} (22 knots), during summer (left) & winter (right) (from (Petro-Canada 1983), based on (Faulkner and Schaefer 1978).

During winter, when cold arctic air collects over northern BC, arctic outbreaks can occur with cold dense air funnelling down the coastal inlets (Kendrew and Kerr 1955). The winds can be very strong, often up to 60 knots, and occasionally to 100 knots. Sustained northeasterly outflow winds have been observed to remain above 60 knots for over 24 hours. The combination of strong winds and frigid temperatures can result in heavy freezing spray within and at the entrances to mainland inlets (Stewart *et al.* 1995). Some inlets, such as Burke Channel, are aligned with the outflows and can have particularly severe cold outflow conditions.

Environment Canada and Fisheries & Oceans Canada maintain an array of weather buoys (Figure B.6). Wind, wave and sea-surface temperature, air temperature and a variety of other data are available real-time via satellite at http://weatheroffice.ec.gc.ca/natmarine/bc/north_coast_e.html and at http://www.ndbc.noaa.gov/station_page.php?station=46204. Lighthouse locations are from the BC Lighthouse website http://fogwhistle.ca/bclights/gps.php.

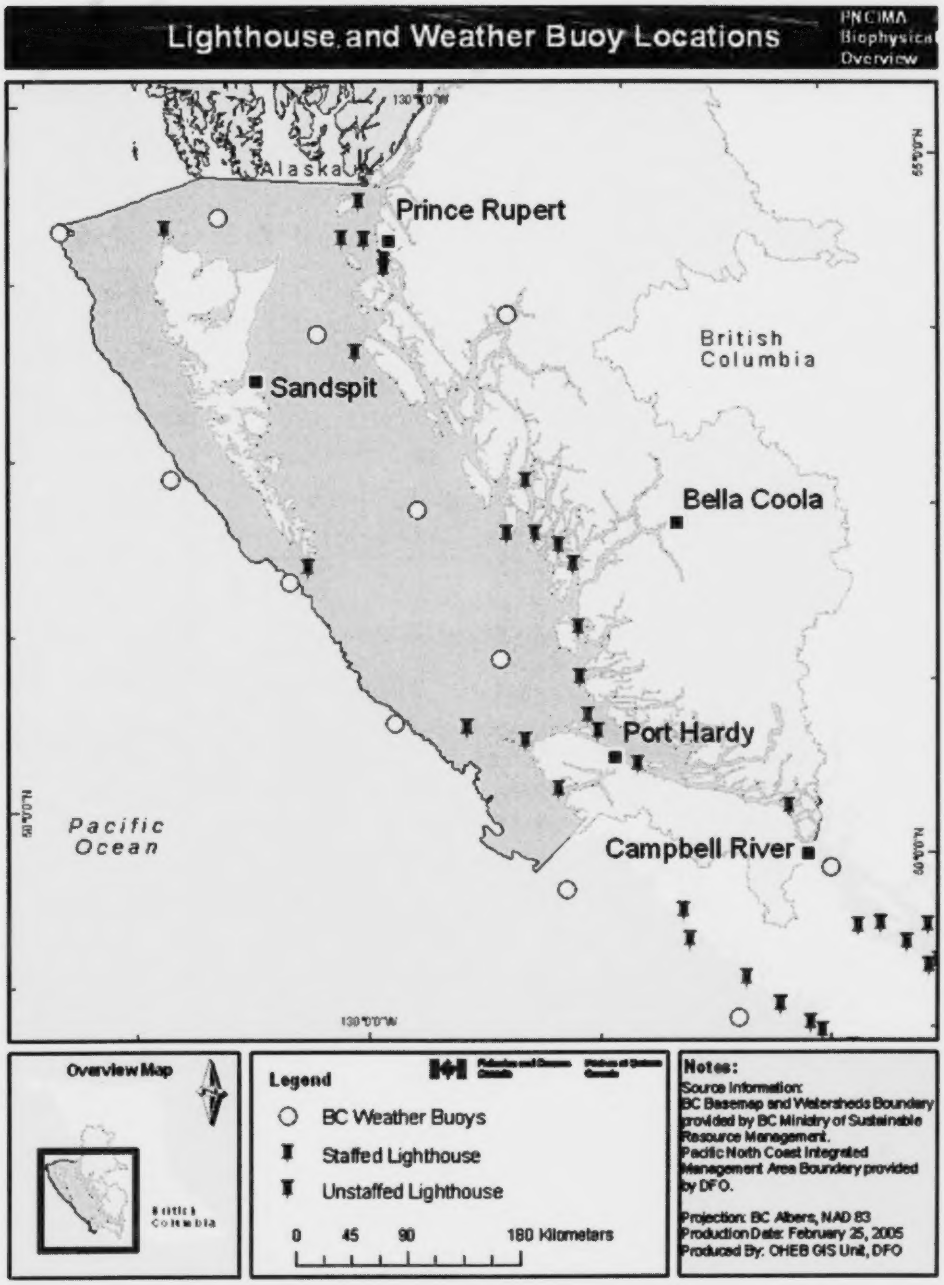

Lighthouse and Weather Buoy Locations
PNCIMA Biophysical Overview
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Prince Rupert
Sandspit
British Columbia
Bella Coola
Port Hardy
Campbell River
Pacific Ocean
Overview Map
British Columbia
Legend
○ BC Weather Buoys
Staffed Lighthouse
Unstaffed Lighthouse
0 45 90 180 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure B.6 The location of BC weather buoys and lighthouses.

3.0 CLIMATE

The coast of BC falls within the Pacific Maritime ecozone (Ecological Stratification Working Group 1996). The climate is moderated by the influence of the Pacific Ocean and affected by the presence of high-elevation mountains along the mainland coast (Meidinger and Pojar *eds*. 1991; Hare and Hay 1974). Mean daily coastal air temperatures range from about 4-5°C in winter to about 13-15°C in summer (Table B.1), the lowest summer temperatures in Canada (Ryder 1989)(Figure B.7). Recorded extremes range from lows of -11 to -17°C during winter to +27 to +32°C in summer. This moderating effect of the ocean causes fairly uniform mild temperatures along the coast, with Vancouver summer temperatures slightly warmer than those of both exposed and protected areas of the central and north coast (Figure B.7). However, higher elevation locations in the PNCIMA watersheds show less moderating influence from the ocean and temperatures are much cooler in winter, though not hotter in summer.

Table B.0 Climatology of the QC Sound region, based on climate normals (1971-2000) for Cape St. James (southern Queen Charlotte Islands), Cape Scott (northern Vancouver Island), & McInnes Island (along central coast) (Environment Canada 2003).

	Cape St James	**Cape Scott**	**McInnes Island**
Air temperatures			
Mean daily	~13°C in July; ~5°C in Jan	~14°C in Aug; ~5°C in Dec-Jan	14-15°C in Jul-Aug; ~4°C in Jan
Extremes	28°C in summer; -14°C in winter	27°C summer; -11°C in winter	32°C in summer; -17°C in winter
Precipitation			
Annual rainfall	1560 mm	2600 mm	2522 mm
Wet months	Oct-Jan (avg. 188 mm)	Oct-Jan (avg. 327 mm)	Oct-Jan (avg. 302 mm)
Dry months	Jun-Aug (avg. 74 mm)	Jun-Aug (avg. 103 mm)	Jun-Aug (avg. 121 mm)
Extreme daily rainfall	Up to 63 mm	Up to 145 mm	Up to 319 mm
Snowfall	~50 cm yearly, mostly Nov-Apr	~50 cm yearly, mostly Nov-Apr	~70 cm yearly, mostly Nov-Apr
Visibility			
Fog days during summer (June-Oct)	10-13	7-13	2-8
Fog days during winter (Nov-May)	5-8	3-5	1-3

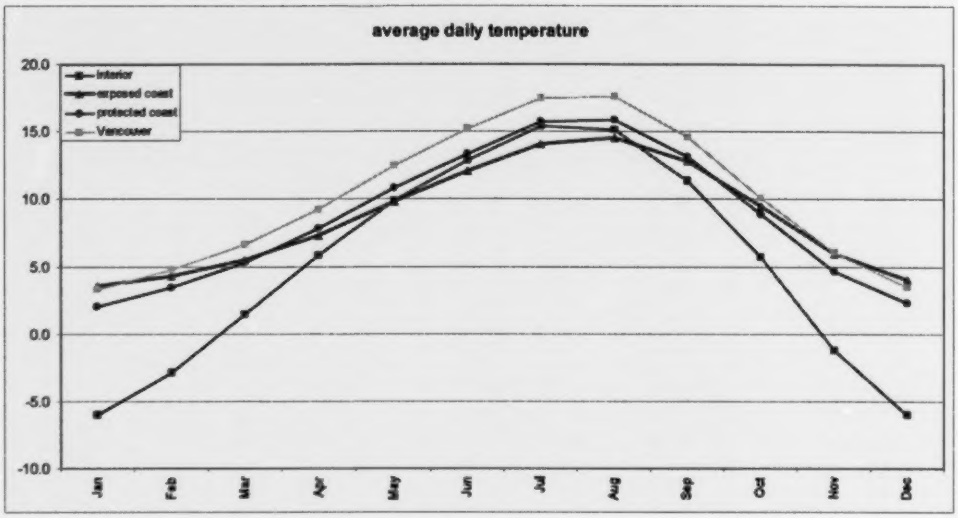
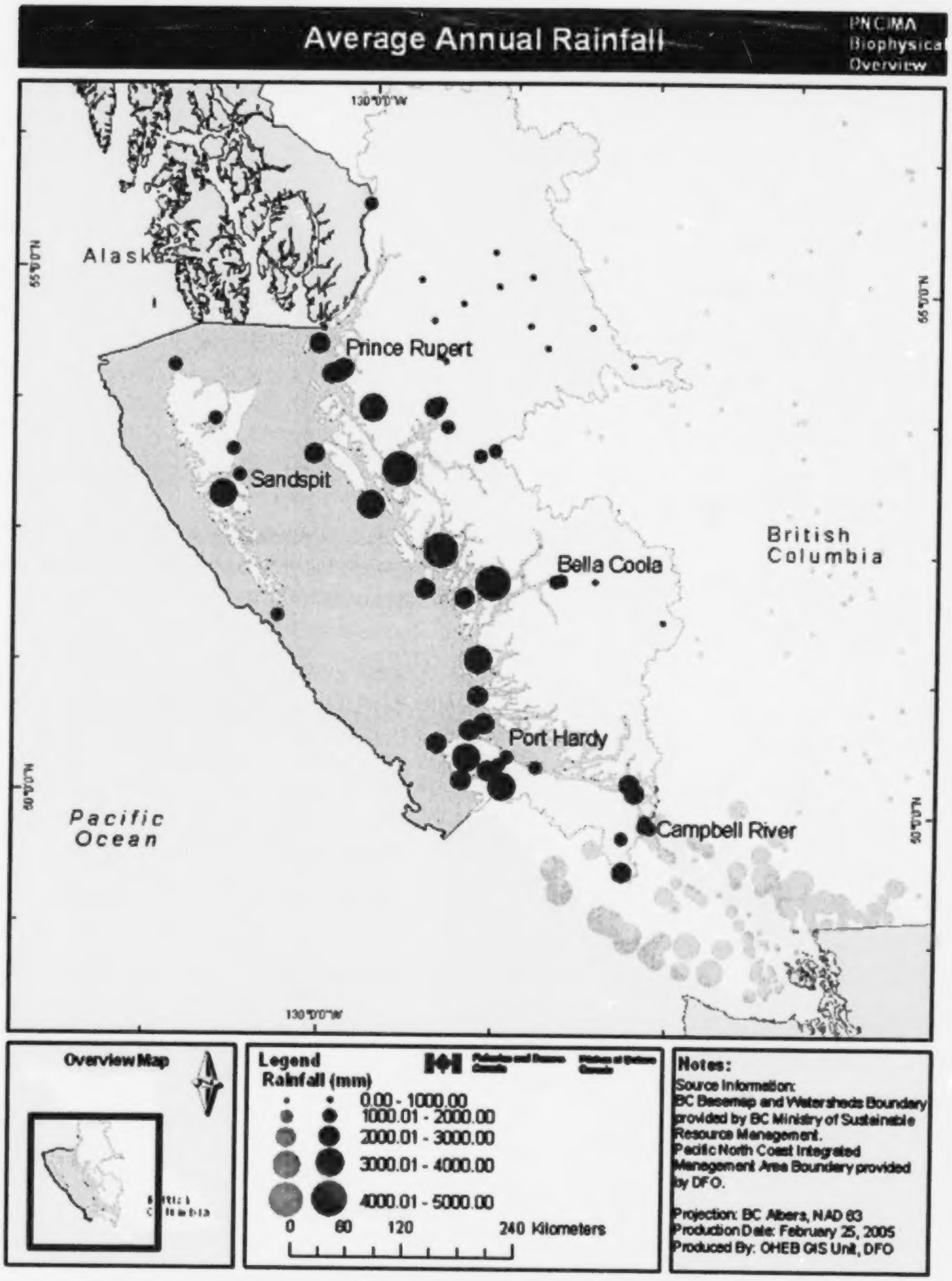


Figure B.7 Average monthly temperatures for climate stations on the protected coast, exposed coast, in elevated interior locations (coastal mountains) and in Vancouver (data from Environment Canada climate normals).

This area receives relatively high amounts of rainfall: 1560 mm annually at Cape St. James, increasing to 2600 mm at Cape Scott. The wettest months are October through January, with monthly average precipitation of 188 mm at Cape St. James, increasing to 327 mm along the mainland coast (~10 mm per day). Extreme daily rainfall can reach 63 mm offshore (Cape St. James), and 319 mm along the coast (McInnes Island). Summers are much drier (74 mm per month at Cape Scott; 121 mm per month along the mainland coast). There is little snowfall at sea level, only 50-70 cm/year, most of which occurs during November-April. The rainfall pattern shows strong orographic effects. Figure B.8 shows that the highest rainfall occurs along the mainland coast at the base of the Coast Mountains. Locations farther from the mountains (mainland islands), or near the lower elevation Queen Charlotte and Vancouver islands mountains, show more moderate to low rainfall levels. Locations in rain shadows show the least rainfall, especially those in the shadow of the coast range (east of Prince Rupert and Bella Coola, Figure B.8).

Visibility can be greatly reduced by fog, particularly during summer and fall. Fog is more common offshore, with 10-13 fog days at Cape St. James during June-October, and decreases towards the mainland coast where McInnes Island has 2-8 fog days.


Average Annual Rainfall
PNCIMA
Biophysical
Overview
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Prince Rupert
Sandspit
Bella Coola
British
Columbia
Port Hardy
Campbell River
Pacific
Ocean
Overview Map
Legend
Rainfall (mm)
0.00 - 1000.00
1000.01 - 2000.00
2000.01 - 3000.00
3000.01 - 4000.00
4000.01 - 5000.00
0
60
120
240 Kilometers

Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.

Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure B.8 Average annual rainfall for climate stations in the PNCIMA and adjacent BC (data from Environment Canada's climate normals).

4.0 CLIMATE VARIABILITY AND CLIMATE CHANGE

4.1 Scales and Measures of Climate Variability

The climate of BC as described above is based on averages of data over long time periods (generally over 30 years of data). However, significant variability exists within that data on a number of time scales. The shortest scale generally discussed is seasonal variability. This refers to changes in the climate from season to season and is captured in the discussion in section 3.0. This seasonal variability is the highest in magnitude because the seasons differ from one another so greatly (winter weather vs. summer weather). Longer scales of variability compare the same months or seasons between different years, decades, etc. or compare annual averages over decades, centuries etc.

Annual variability refers to the differences in monthly or seasonal data between different years. These differences are largely a result of variation in the position and strength of the Aleutian Low and North Pacific High pressure systems. These variations can have a significant effect on oceanographic conditions and on biological functions in the coastal ecosystem.

In addition to this 'normal' or local annual variability, climatic changes in other parts of the world can disrupt local weather patterns on scales of a few months to a few years and are often termed interannual variability. El Niño is the most well known of these effects and its pattern of change is called the El Niño Southern Oscillation (ENSO). A change in trade winds causes a reduction in upwelling of cold waters off the coasts of Ecuador and Peru with resulting added heat and moisture brought into these normally arid countries from the central Pacific. The western equatorial Pacific experiences drier weather and these tropical conditions alter the weather in extra-tropical regions. For PNCIMA, this generally results in a milder and wetter winter except for portions of the Central Coast. The Environment Canada Web page below lists impacts of El Niño in Canada: http://www.msc-smc.ec.gc.ca/education/elnino/canadian/index_e.cfm. The ENSO index is used by oceanographers to monitor and predict changes in ocean conditions in the North Pacific (further detail in Appendix C: Physical and Chemical Oceanography).

Decadal variability refers to changes that take place in tens of years. The Pacific Decadal Oscillation (PDO) is an example of this kind of climate variability that affects Canada's Pacific coast. The PDO is developed from analysis of sea surface temperature anomalies in the Pacific Ocean north of 20°N. Changes associated with this index have recently been linked to the concept of 'Regime Change', which refers to large scale changes seen in many parts of the ecosystem that may reflect a change from one relatively stable ecosystem state to another. The Aleutian Low Pressure Index (ALPI) is related to the PDO but is a more direct measure of winter-time sea surface air pressure in the northeast Pacific, and thus a measure of the intensity of the Aleutian Low in winter (Beamish *et al.* 1997).

Variability on longer time scales approaches the geological time scale. The entire Quaternary Period (~ last 2 million years) is defined as a time of climate variability on the scale of tens to hundreds of thousands of years cycling between glacial advances and retreats during cold and warm periods (see Appendix A: Geology 1.0). This scale of variability is too long to be of use in management or planning processes.

4.2 Climate Change

Climate Change is a term often used to refer to alterations in the climate that are understood to be anthropogenic in nature. In particular, it is clear from recent studies that we are in a time of global warming. Warming of the globe is not in itself unusual in the geologic record, however, the current rate of warming is believed to be completely unprecedented in human experience (Figure B.9). Warming results from the steady increase in atmospheric greenhouse gases such as CO_2, methane, ozone and others. A greenhouse gas lets in solar energy to the surface of the earth, but absorbs radiation at wavelengths that are emitted from the earth. When concentrations of these gases are increasing, the earth gains more heat energy than it releases. Much greater detail on this topic can be found in the publications of the Intergovernmental Panel on Climate Change (IPCC) at http://www.ipcc.ch/ particularly in its report on the scientific basis of climate change (Intergovernmental Panel for Climate Change 2001). Increases of greenhouse gases will clearly have significant and increasing effects on the structure and function of ecosystems all over the globe.

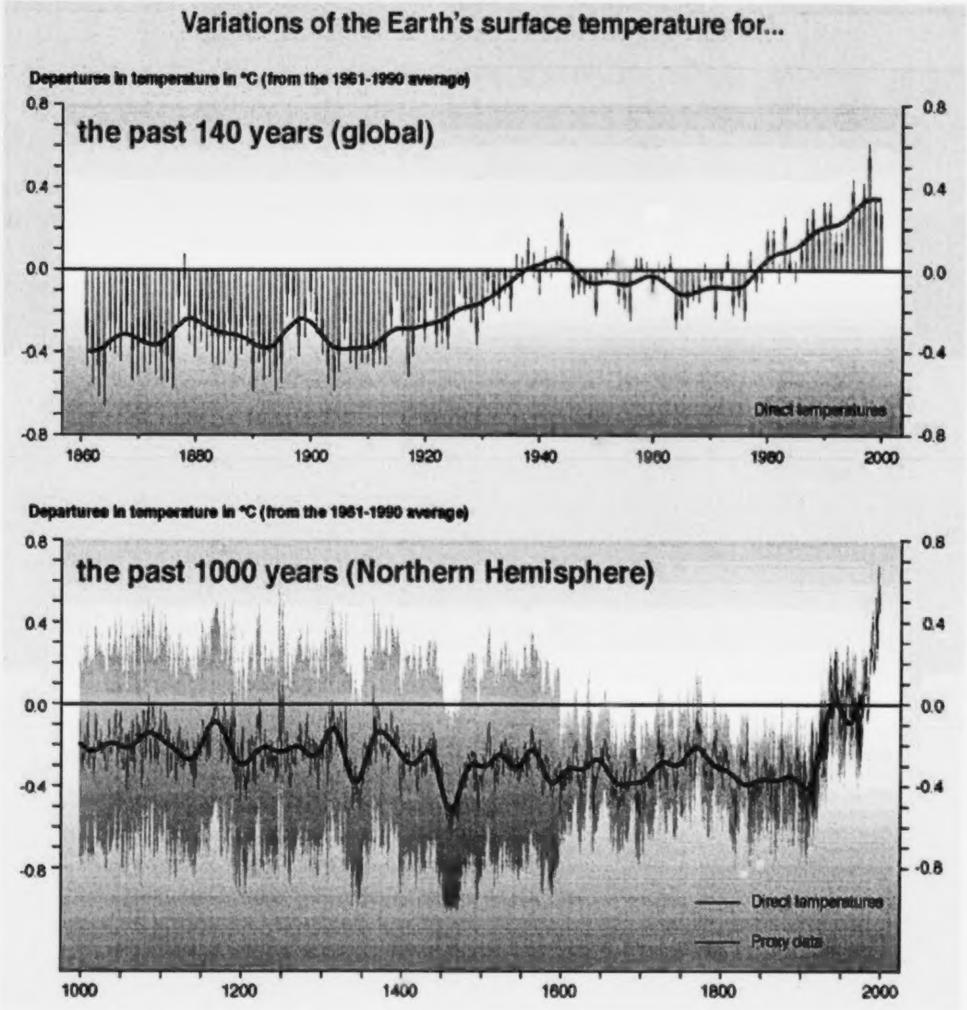


Figure B.9 Global air temperature change from 1861 to 2000 and northern hemisphere temperature change from 1000 to 2000 AD (figure from IPCC synthesis report acquired from the website http://www.ipcc.ch/present/graphics.htm).

5.0 GLOSSARY

Orographic effect - Rainfall that results from or is enhanced by mechanical lifting of an air mass over mountains.

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Canadian Technical Report of
Fisheries and Aquatic Sciences 2667

2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX C: PHYSICAL AND CHEMICAL OCEANOGRAPHY

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1.0 INTRODUCTION

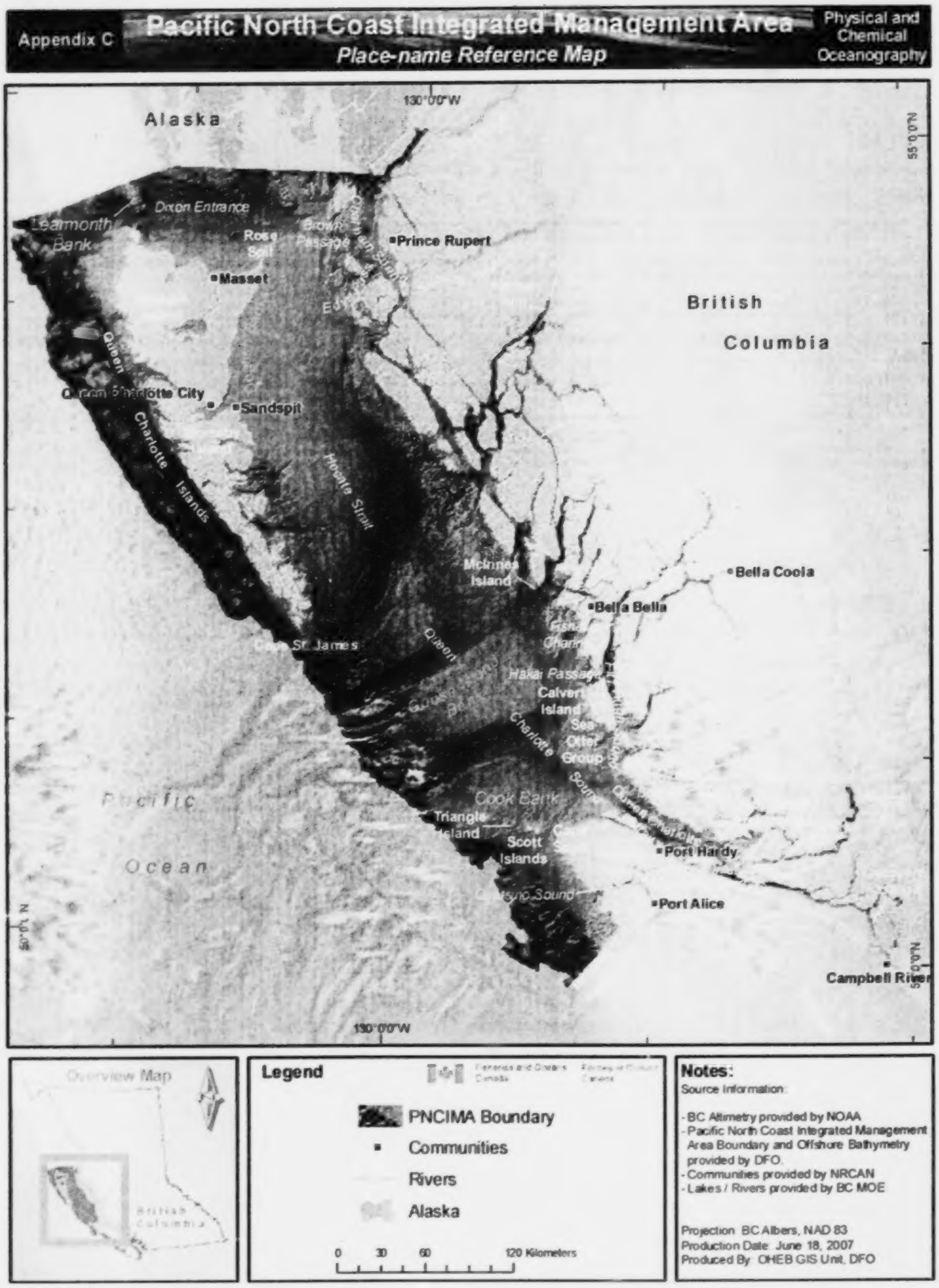
Oceanography generally refers to the basic physical and chemical characteristics of the ocean as well as to plankton productivity. These characteristics define ocean conditions that can be critical to the health and productivity of the marine biota. Ocean waters circulate and are mixed by various large scale and small scale physical processes. These especially include solar heating and surface winds, and also freshwater inputs and tidal mixing in coastal waters. Physical and biological processes create strong gradients of chemical parameters such as nutrients and oxygen that are essential to life in the ocean. These ocean properties define conditions that are critical to the health and productivity of marine biota. Thus an understanding of basic oceanographic processes is critical to understanding ecosystem function.

The PNCIMA area (Figure C.0) lies at the transition zone between two large circulating gyres in the Northeast Pacific Ocean, the cool Alaskan and warm East Pacific Gyres. Both gyres bring waters from west to east across the Pacific with this flow splitting off the British Columbia (BC) coast into a northern (Alaska Current) and southern branch (California Current). The location of the separation varies with atmospheric conditions because the gyres are largely wind driven, with the Alaska Gyre generally being larger and stronger in the winter, and the East Pacific Gyre dominant in the summer.

Coastal currents are driven by winds and freshwater discharges from land, and are strongly controlled by coastal morphology and continental shelf bathymetry. Estuarine circulation denotes the process in which runoff-driven currents in the summer carry surface waters out of coastal inlets, resulting in a counter-current of deeper ocean water flowing shoreward over the shelf along the deep troughs and into inlet basins in the PNCIMA area. Surface flows are fresher; deeper flows are saltier and generally richer in nutrients. Winter coastal currents are dominantly northwards in PNCIMA and tend to transport waters quickly through the area; however eddies act to retain surface waters in some regions. Currents are weaker and more variable in the summer.

The coastal inlets are dominantly fjords and so are often restricted from interactions with open waters by shallow sills and narrow entrances. Water properties within these inlets are quite distinct from more open shelf waters because of their isolation. In inlet basins with very weak circulation, anoxia can periodically occur to the detriment of most marine animals.

All of these conditions are further complicated by variability in the climate and weather. El Niño conditions, which occur every several years, can significantly change the 'normal' conditions of a given season by transporting southern organisms and fishes into the PNCIMA region and by raising ocean temperatures. Changes on a longer scale include decadal oscillations and "regime shifts", which are thought to significantly affect biological productivity in the region. Additionally, global warming is seen to be affecting ocean conditions, most obviously increasing sea surface temperatures over at least the last 50 years.


Appendix C
Pacific North Coast Integrated Management Area
Place-name Reference Map
Physical and Chemical Oceanography
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
British Columbia
Pacific Ocean
Dixon Entrance
Learmonth Bank
Rose Spit
Brown Passage
Chatham Sound
Prince Rupert
Masset
Queen Charlotte Islands
Queen Charlotte City
Sandspit
Hecate Strait
McInnes Island
Bella Coola
Bella Bella
Hakai Passage
Calvert Island
Sea Otter Group
Cape St. James
Goose Bank
Queen Charlotte Sound
Cook Bank
Triangle Island
Scott Islands
Quatsino Sound
Port Hardy
Port Alice
Campbell River
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Rivers
Alaska
0
30
60
120 Kilometers

Notes:
Source Information:

- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE

Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure C.0 PNCIMA region showing locations and features of BC waters.

1.1. Key Points

- The coast of BC lies at a transition zone between two large Pacific gyres. The transition zone migrates north and south depending on the dominance of the atmospheric pressure systems whose winds drive the gyres (Appendix B: Meteorology and Climate).
- Coastal currents are largely wind- and freshwater-driven, and are controlled by the coastal morphology and the bathymetry of the continental shelf. Wind conditions (and therefore the currents) tend to be quite seasonal, having different summer and winter conditions.
- Overall, BC waters are warming. This is likely to have a negative impact on the health of some cool water organisms, while allowing southern species to thrive in BC waters.
- Oxygen levels are declining in deep waters seaward of the continental shelf. In warm years such as 1998, it appears that oxygen depletion is more prevalent in inlets on the coast. Such trends and episodes must have impacts on fisheries and ecosystems, although the BC north coast lacks data to adequately make this connection.

1.2. Major Sources of Information or Data:

- Richard Thomson's "Oceanography of the British Columbia Coast' is generally considered the best overall synopsis of physical oceanography of the BC coast, and despite being more than 20 years old, is still frequently referenced (Thomson 1981). An update of the information of the Queen Charlotte Islands was produced in 1989 (Thomson 1989), and a recent compilation of oceanic data for northern PNCIMA was produced in 2001 (Crawford 2001).
- A review of the oceanographic and geological setting of the Queen Charlotte Basin was compiled by Cretney *et al.* (2002). Reviews of numerical modelling capability for oil and gas issues were prepared by Crawford *et al.* (2002b) and by Foreman *et al.* (2005).
- A compilation has been made of physical, chemical and biological oceanographic data for the majority of the study area for the purpose of assisting in the ecosystem approach to fisheries management in Hecate Strait (McQueen and Ware 2002). Whitney *et al.* (2005a) compiled a review of nutrient supply processes along the margins of the Gulf of Alaska, including PNCIMA.
- The Institute of Ocean Sciences (IOS) has a significant concentration of expertise and archived data on BC oceanography. In particular, some long time series data, such as the lighthouse temperature and salinity measurements and the Line P program, are critical to understanding ocean variability and change (http://www-sci.pac.dfo-mpo.gc.ca/osap/data/default_e.htm).

- DFO is producing annual summaries of oceanographic conditions of the coast of BC through the Pacific Science Advice and Review Committee (DFO 2005). In these 'State of the Ocean' reports there is a strong focus on seasonal, annual, and decadal scale variability with information on significant changes in plankton, marine birds, and some fish species also presented http://sci.info.pac.dfo.ca/PSARC/OSR's/OSR.htm.
- Summaries of oceanographic information for the broader northeast Pacific include a book by PICES (2004), and Hood and Zimmerman (1986). Oceanographic summaries are included in the reports on Oil and Gas development in BC's north and central coast area (Petro-Canada 1983; Chevron Canada Resources Ltd. 1982; Jacques Whitford Environment Ltd. 2001; Strong *et al.* 2002; Cretney *et al.* 2002; Hall *et al.* 2004).
- Three reviews of Canadian physical oceanographic research have been completed for the time periods 1991-1994 (Gratton 1995), 1995-1998 (Foreman and Gratton 1999), and 1999-2002 (Stacey and Crawford 2003). These list activities and relevant publications on physical oceanography in Canada.
- Fairly detailed oceanographic information is also included in the feasibility reports by the province for salmonid farming in the north and central coast areas (Ricker *et al.* 1989; Ricker and McDonald 1992; 1995).

1.3. Uncertainties, Limitations, and Variability

Most oceanographic research is based on limited data that is extrapolated to cover vast areas. Few long-term time series exist. The PNCIMA area in particular is remote from large population centres and expensive to study. Harsh winter conditions mean that much of our knowledge comes from summer surveys. Technology such as satellite images are improving some areas of knowledge, but often require ground-truthing and can not 'see' far below the surface of the ocean. Models also allow us to develop an understanding of conditions over a large area, but again, observations are critical to the verification of their results.

Our knowledge of the waters of the Gulf of Alaska is improving thanks to Project Argo, an international project to monitor ocean currents and water properties. Several thousand autonomous profilers have been launched into the global oceans, including the Gulf of Alaska. Their direct impact on the PNCIMA region is minor because they drift in waters only deeper than 2000 m.

The interannual variability of oceanographic conditions is generally not predictable with the exception of El Niño conditions which may be predicted three to six months ahead.

1.4. Identified Knowledge and Data Gaps

- Monitoring of ocean conditions in selected inlets and on the continental shelf of the northern BC coast would provide information on episodic events or longer term trends that may disrupt ecosystems. Modern mooring systems can provide a wide range of information which can be transmitted via satellite.
- Integrating fisheries and oceanographic surveys would improve our understanding of the sensitivity of fishes to ocean variability. For example, the oxygen tolerance of many groundfish is unknown.
- Improved models of tides, currents, the sound environment and other oceanographic characteristics of the region would assist in predicting impacts of climate or human activities.
- Developing clear and consistent links between oceanographic conditions and the survival of marine ecosystems is an essential area of research.

2.0 CURRENTS AND CIRCULATION

2.1. Large-Scale Offshore Circulation

The Subarctic Current is a large, slow (~5-10 cm/s), trans-Pacific current that splits into two branches offshore of the Pacific Coast: the Alaska Current and the California Current (Figure C.1). The Subarctic Current is also referred to as the West Wind Drift or the North Pacific Current. The Alaska Current curves to the north into the Gulf of Alaska and flows around the Alaskan Gyre, while the California Current veers southward and flows around the East Pacific Gyre.

The strength, position and size of the gyres vary seasonally as they are driven by the atmospheric Aleutian Low and North Pacific High pressure systems (see Appendix B Figure B.1). Thus, the Alaska Current intensifies in winter due to the strengthening of the Aleutian Low (Figure C.1, upper panel). This seasonal variation moves the location of the divergence of the Subarctic Current, which can be found as far north in summer as the Alaskan Panhandle, and as far south in winter as the coasts of Washington and Oregon (Figure C.1, lower panel). The location of this divergence is significant because currents in the northern hemisphere are turned to the right by the Coriolis force. Thus currents moving northward are pushed towards the coast and create a downwelling environment where low-nutrient surface waters build up against the coast and denser, high-nutrient waters are pushed to deeper depths. For this reason downwelling is often associated with reduced ocean productivity. Southward moving currents are turned away from the coast and create an upwelling environment where deep ocean waters are brought to the surface along the coast. These waters are rich in nutrients and so are responsible for creating areas of enhanced ocean productivity. PNCIMA coastal regions experience strong downwelling in winter and weak upwelling in summer. In addition to upwelling, tide- and wind-driven mixing are a significant factors in the supply of nutrients to the surface ocean and oxygen to bottom waters over the continental shelf.

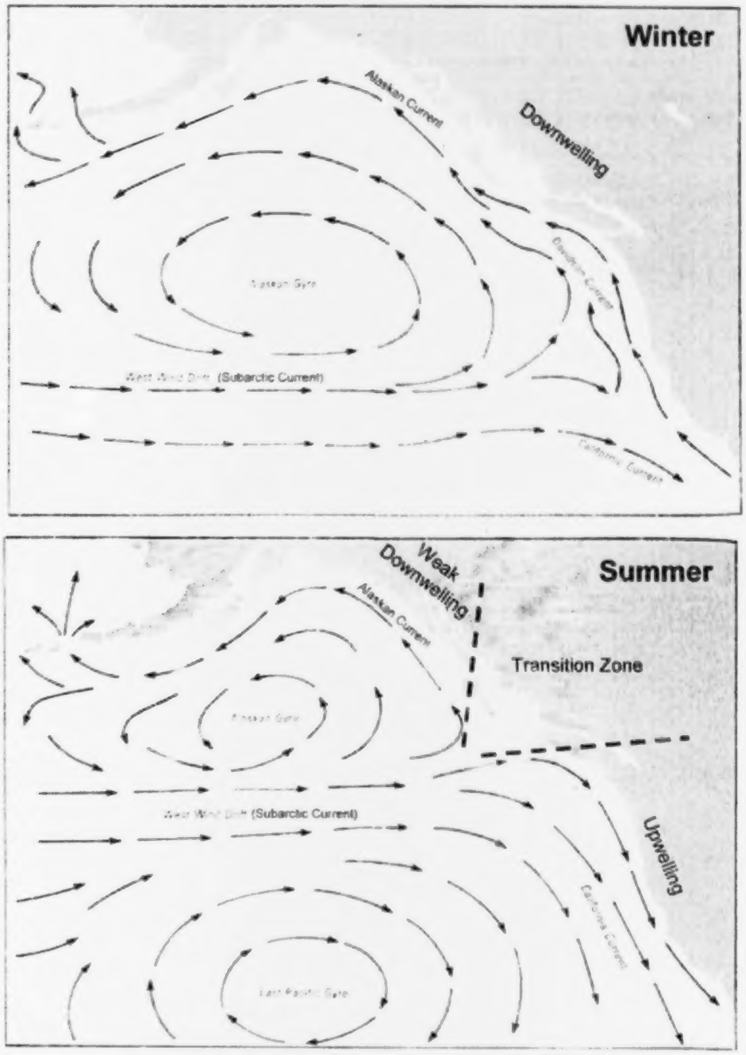

Winter
Alaskan Current
Downwelling
Alaskan Gyre
Davidson Current
West Wind Drift (Subarctic Current)
California Current
Summer
Weak Downwelling
Alaskan Current
Transition Zone
Alaskan Gyre
West Wind Drift (Subarctic Current)
Upwelling
California Current
East Pacific Gyre

Figure C.1 Ocean circulation in the northeast Pacific in summer and winter (figure modified from Chevron Canada Resources Ltd. 1982).

2.2. Circulation off the Central and Northern BC Coast

Ocean currents off central BC are driven by a combination of tidal currents (due to the gravitational attraction of the sun and the moon on the ocean) and non-tidal currents (wind-driven, runoff/buoyancy driven, bathymetric steering, etc.). Tidal currents generally dominate the water movement over time scales of hours; however their oscillatory motion (the ebb/flood cycle) can result in little net movement. Tidal flows are often masked by wind-driven and buoyancy/estuarine currents.

The speed and direction of the currents are modified by the bathymetry and coastline. The central BC shelf region is dominated by a series of banks and troughs, remnants of glacial scouring. These features modify and steer the tidal and non-tidal flows.

The average currents along BC's continental slope can flow either north or south depending on the wind patterns and the forcing of cross-shelf sea surface slope due to coastal runoff of fresh water. These currents are stronger than those further offshore and are generally seasonal in nature. In winter, the Davidson Current flows northward off Vancouver Island, extending to Queen Charlotte Sound (Figures C.1 upper and C.2a). Queen Charlotte Sound may disrupt the alongshore coherence of this current (Yao *et al.* 1984). The northerly flow off the northwest coast of the Queen Charlotte Islands, termed the Haida Current, is driven by the wind and the alongshore sea surface slope (Thomson and Emery 1986; Thomson 1989). It is warmer than the surrounding waters by about 1-2°C (Thomson 1989). In summer, with the weakening of the Aleutian Low, these shelf break currents weaken, often reversing to southerly flow (Figure C.2b).

The Vancouver Island Coastal Current flows northward along Vancouver Island, close to shore (Thomson *et al.* 1989). In winter, southeasterly winds tend to push this current past Brooks Peninsula, but in summer this current is often turned back at Brooks Peninsula by the physical barrier of the peninsula, and by wind driven currents moving southward (Figure C.2b). Brooks Peninsula is also thought to scatter coastal-trapped shelf waves (Yao *et al.* 1984).

2.3. Tidal Currents

The large tides of the BC coast generate strong tidal currents. These currents dominate the surface flows and result in strong tidal mixing, particularly over the banks in Queen Charlotte Sound and shallow portions of Hecate Strait, around the southern and northeastern tips of the Queen Charlotte Islands (Cape St. James and Rose Spit), and the western end of Dixon Entrance (Figures C.3-C.6).

As discussed in detail in section 4.0, diurnal and semi-diurnal constituents dominate the tidal currents along the BC north and central coast. Variability also occurs at fortnightly periods as can be seen in Figures C.12 and C.13 (the spring/neap cycle of large and moderate tidal range), and over monthly and seasonal time scales.

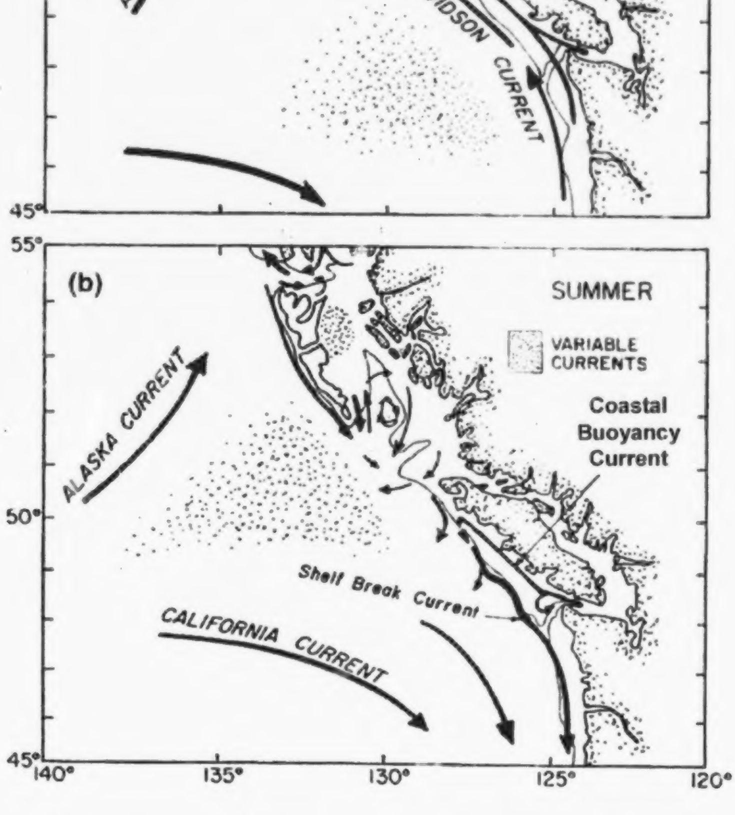

55°
(a)
Haida Current
WINTER
ALASKA CURRENT
50°
DAVIDSON CURRENT
45°
55°
(b)
SUMMER
VARIABLE CURRENTS
ALASKA CURRENT
Coastal Buoyancy Current
50°
Shelf Break Current
CALIFORNIA CURRENT
45°
140°
135°
130°
125°
120°

Figure C.2 Ocean circulation off BC in summer (b) and winter (a) (from Thomson 1989).

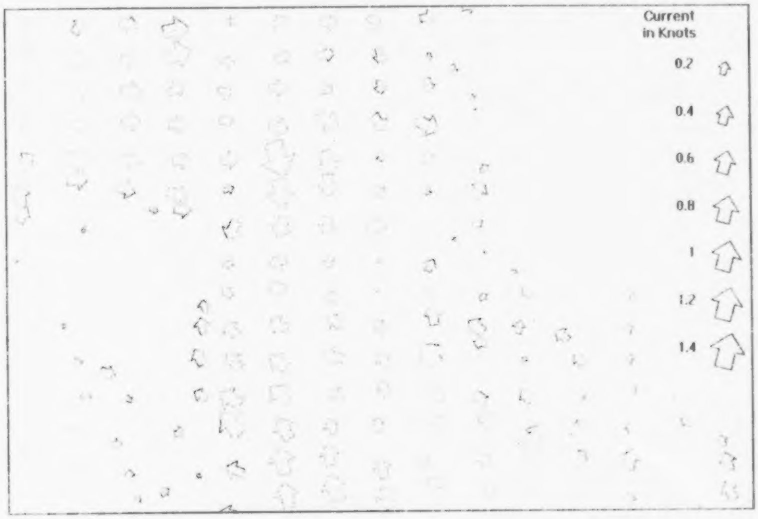


Figure C.3 Model results of flood tide currents in northern Hecate Strait and Dixon Entrance (from Crawford 2001).

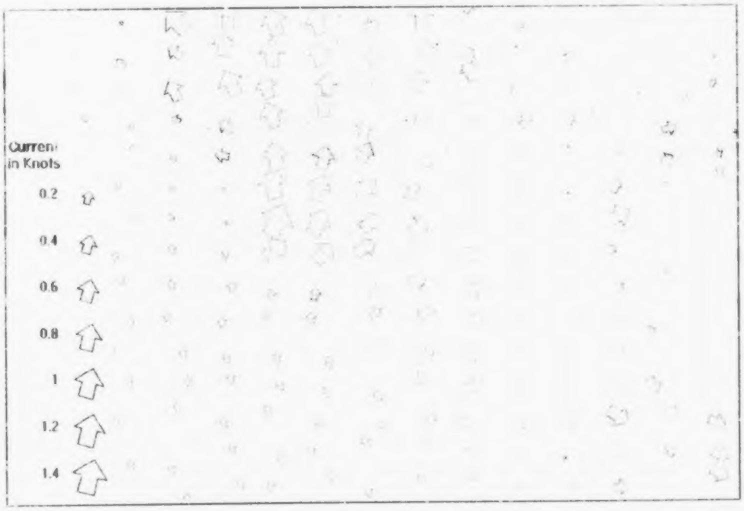


Figure C.4 Model results of flood tide currents in Queen Charlotte Sound and southern Hecate Strait (from Crawford 2001).

Figure C.5 Model results of ebb tide currents in northern Hecate Strait and Dixon Entrance (from Crawford 2001).

Figure C.6 Model results of ebb tide currents in Queen Charlotte Sound and southern Hecate Strait (from Crawford 2001).

The tide floods into Queen Charlotte Sound, then turns northwards and progresses up Hecate Strait (Figure C.14); the ebb outflow is in the opposite direction. The flood/ebb tidal currents are rotary-clockwise in open seas, becoming more rectilinear in channels and when confined by the bathymetry/shoreline. Tidal currents become weaker with depth, suggesting that density effects are important. It is thought that baroclinic tides or internal waves (discussed below) are probably generated by interaction of the tide and the shelf bathymetry in this area (Thomson 1989).

Tidal currents generally have speeds of about 0.5 m s^{-1} during the large spring tides and about half that during the weaker neap tides. The tidal flows are stronger off Cape St. James, up to 2 m s^{-1}; however, they are often masked by the strong outflow current there (Figure C.7). Model results by Foreman (M. Foreman, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2004) also show enhanced tidal current speeds over the shallow banks and around points of land such as Rose Spit at the northeast tip of the Queen Charlotte Islands. Mariners have observed overfalls east of Rose Spit, whose current speeds have not been determined.

During spring tides, the strong tidal currents over the shallow banks remove any near-surface stratification, particularly over Goose Island Bank and Cook Bank, and to a lesser extent off Cape St. James (Jardine *et al.* 1993). This mixing can bring deeper, nutrient-rich water up to the surface where it is available to phytoplankton. Tidal fronts often define the boundaries of these well-mixed regions, and these frontal zones tend to concentrate plankton. This, in turn, attracts fish, birds and other marine life. The Scott Islands are home to three Stellar sea lion rookeries, partly due to the remoteness of these islands, but also due to the high productivity of the surrounding waters (see Appendix J: Marine Mammals and Turtles). Triangle Island in the Scott Islands supports the largest and most diverse seabird colony of the entire BC coast (see Appendix K: Marine Birds).

Tidal currents can be large in restricted channels; drifters passing through the restricted passages near Cape St. James moved at speeds up to 2 m s^{-1} (Crawford 1997). In Johnstone Strait (Thomson 1981) turbulent tidal flows reach speeds of 1.5 m s^{-1}, with well-defined tidelines delineating transitions to weaker flows. Within the coastal inlets and fjords, the tidal currents generally weaken, but can be strong in some of the narrow coastal passageways. For example, maximum tidal currents are:

- 7.5 m s^{-1} in Nakwakto Rapids at the entrance to Seymour/Belize Inlets (Canadian Hydrographic Service 2002).
- 2.3 m s^{-1} in Hiekish Narrows between Princess Royal and Finlayson channels (Canadian Hydrographic Service 2002).
- Up to 3.6 m s^{-1} in Chatham Channel at the outlet of Call Inlet (Pickard 1961; Canadian Hydrographic Service 1984).
- Up to 2 m s^{-1} in parts of Quatsino Sound and up to 4.4 m s^{-1} at Quatsino Narrows (Ricker *et al.* 1989).

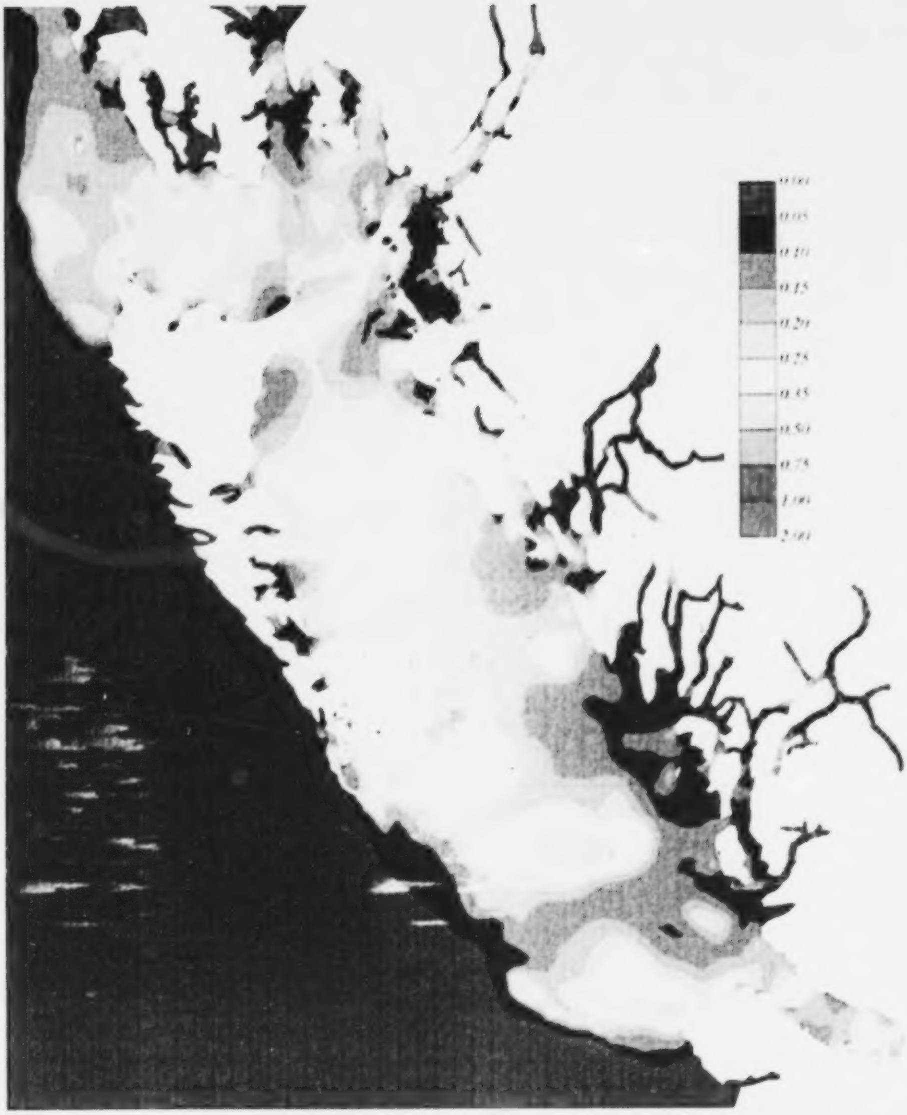

0.00
0.05
0.10
0.15
0.20
0.25
0.35
0.50
0.75
1.00
2.00

Figure C.7 Maximum tidal speeds, rms (m s^{-1}), modelled results from Foreman (M. Foreman, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2004), based on an updated version of the northeast Pacific tidal model described in Foreman *et al*. (1993).

2.4. Wind-driven Currents

Because of the large-scale atmospheric pressure systems offshore, and their resulting regional wind forcing, there is a strong seasonal nature in the wind-driven current patterns. The winter southeasterlies result in a general northerly flow of water through Queen Charlotte Sound and southern Hecate Strait (Crawford 2001; Cretney *et al.* 2002). The net transport has been estimated at 300,000 $m^3 s^{-1}$ (Crawford *et al.* 1988). It has been found that winters with strong currents through Hecate Strait coincide with generally poor recruitment years for Pacific cod (Tyler and Crawford 1991; Sinclair and Crawford 2005). Conversely, during the weaker, generally northerly winds of summer, the currents are more variable and there is little net transport through Hecate Strait (Crawford *et al.* 1988).

Inertial currents are generated mainly by the passage of storms that provide a 'push' to set the inertial currents in motion. These currents can be substantial within Queen Charlotte Sound and Hecate Strait and can be coherent across the width of the sound (Thomson 1981). The strongest current speeds are up to 0.5 m s^{-1} near the entrance to Queen Charlotte Sound, reducing to about 0.3 m s^{-1} in the eastern part of the sound. They are concentrated in the near-surface layer, but remnants extend down as far as 250 m. The current vectors rotate in a clockwise direction with one rotation every ~15.5 hours, which is the inertial period at 51°N.

Successive storms, with peak winds separated by ~4 inertial periods, were observed to keep the inertial currents in motion for nearly 12 days in June 1977 (Thomson 1981).

2.5. Wind-induced Upwelling/Downwelling

Winds from the southeast dominate during winter (Oct-Apr). These winds push surface water northward into Hecate Strait, raising sea level all along the strait, with higher levels in the shallow, narrower northern end. In addition, Coriolis force causes these surface currents to veer to the right raising sea level a little more along the eastern side, and a little less along the west side of Hecate Strait. As surface wind-forced currents veer to the right they also displace deeper waters which in turn flow westward toward mid-strait. This downward displacement of surface water toward the bottom is denoted 'downwelling'. The combination of wind mixing and downwelling in winter creates a well-mixed water column in many regions of Hecate Strait, increasing the dissolved oxygen content of the bottom waters on this continental shelf. The reverse process, when winds blow from the south and bring deeper waters to the surface, is denoted 'upwelling'.

Along the central and northern BC coast, weak upwelling may occur during the summer (June-Aug) as shown in Figure C.8, although *in situ* oceanographic data does not show evidence of deeper waters being drawn towards the surface on this continental shelf. The constant supply of fresh water into the coastal ocean may inhibit any upwelling that could occur in summer. However, the summer winds are generally mild and often instead of upwelling, PNCIMA experiences a relaxation of winter downwelling. This relaxation can still result in deep ocean waters brought all the way to the surface if tidal mixing is able to mix down to the deep ocean waters that are have been brought near to the surface.

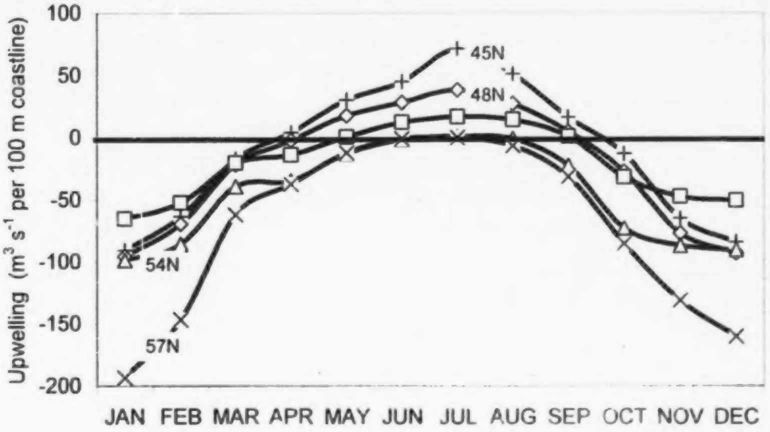


Figure C.8 Monthly upwelling index showing the seasonal pattern of upwelling in summer and downwelling in winter at several locations along the west coast (data from the NOAA web site: www.pfeg.noaa.gov/products/).

The deep ocean waters are higher in nutrients than the surface waters, but lower in dissolved oxygen. Oceanic waters enter deep troughs in Queen Charlotte Sound and Hecate Strait as they move on to the continental shelf (Whitney *et al.* 2005a). These dense waters penetrate the coastal inlets as well, flushing them with nutrient-rich, low oxygen water.

2.6. Internal Waves

The water column often exhibits cyclical oscillations in current and other water properties due to internal waves. Internal waves are like waves at the surface but instead of occurring at the air-water interface, they occur at the interface of water masses of different densities (layers in the water column) such as the thermocline. Compared to surface waves, the density differences within the water column are minor, allowing large amplitude fluctuations. They generally result from the interaction of the tide with bathymetric features such as the shelf break (Cummins and Oey 1997). These baroclinic tides are actually long-period internal gravity waves with the same period as the tide (Thomson 1981). Internal tides are most evident in Dixon Entrance and Queen Charlotte Sound near the shelf break, but reduce in magnitude toward the shallow waters of northern Hecate Strait (Crawford *et al.* 1998). Sills at the entrance to many inlets can also produce internal waves. These often have surface signatures, perhaps the most well known occurring at the entrance to Knight Inlet. Internal waves at Hakai Pass may be related to a cross-channel flow (Province of British Columbia 1998). These internal waves produce an up and down movement at the density interface that can be tens of meters while the surface expression is negligible. These waves can also cause surface currents of one or more knots (one knot is about 0.5 metres/second), especially in Dixon Entrance (Crawford and Greisman 1987; Crawford *et al.* 1998).

It has been speculated that plankton interact with internal waves, possibly to their advantage, as concentrated bands of plankton have often been observed moving slowly shoreward (http://spiff.ucsd.edu/iwave.html) (Mackas et al. 2003).

2.7. Runoff and Estuarine Flow

The west coast of North America receives large volumes of freshwater runoff from several major rivers, including the Columbia, which enters the Pacific at 47°N, and the Fraser, which enters the Strait of Georgia at 49°N. These buoyant waters (less dense than seawater) initiate a coastal current that moves northwards along the Washington, BC and Alaska coasts (Thomson 1989). They subsequently feed the Alaska Coastal Current that flows counter-clockwise around the Gulf of Alaska on the continental shelf from northern BC through Alaska. (The **Alaska Current**, noted earlier, flows in deep-sea waters offshore of the **Alaska Coastal Current**, which is confined to the continental shelf.) This buoyancy-driven current system serves as a migratory corridor and habitat for salmon and other marine organisms, and may advect climate signals (particularly fresh water) over vast distances (Weingartner *et al.* 2001).

The BC coast receives direct discharge from many smaller rivers (partial listing in Table C.0). Much of the runoff into Queen Charlotte Sound enters at Fitz Hugh Sound, fed by outflow from Rivers Inlet, North and South Bentinck arms and Fisher-Dean channels. It was noted by Ricker and McDonald (1995) that the annual discharge from the Fitz Hugh Sound system is large, being about 63% of that of the Fraser River. Runoff to northern Hecate Strait and Dixon Entrance is dominated by the significant Skeena and Nass rivers. The months of peak river discharge are listed in Table C.0.

In summary there appear to be three types of river discharge into PNICMA waters. Large-watershed rivers, such as the Skeena and Nass, have high overall discharge and their broad peak is in the spring and early summer as a result of snowmelt. At the opposite extreme are the small-watershed rivers of the Queen Charlotte and Vancouver islands that have low annual flows and are dominated by rainfall, especially in late autumn and winter. This results in low summer flows and numerous sudden peaks through the autumn and winter as a result of storms. Between these extremes are the small to medium sized rivers along the mainland coast. Many of these watersheds include snowfields and glaciers providing high summer flows, sometimes even peaking in late summer if they are glacier dominated. However, these rivers are also significantly affected by rainfall and their storm-related flows in late autumn and winter can rival their summer flow level.

Table C.0 Estimated discharge of selected coastal rivers in the PNCIMA area. Sources: (Water Survey of Canada 1982; LeBlond et al. 1983; Environment Canada 2002). More detailed data are available on the HYDAT CD-ROM (Water Survey of Canada 1996). The Fraser River is included so as to provide a reference scale.

Basin **River**	**Station ID**	**Drainage Area (Km^2)**	**Mean Annual Discharge $(m^3 s^{-1})$**	**Time of High Discharge**	**Maximum Discharge Event $(m^3 s^{-1})$**	**Time of Max Event**	**Record Duration**
Dixon Entrance							
(Mainland)							
Nass River	08DB001	18500	**821.0**	May-June	9460	Oct	1958-
Skeena River	08EF001	42200	**913.0**	May-June	9340	May	1928-
Zymoetz River	08EF005	2980	**106.0**	May-June	1980	Nov	1963-
Exchamsiks River	08EG012	370	**43.7**	June-July	572	Oct	1962-
(East Side Queen Charlotte Islands)							
Yakoun River	08OA002	477	**30.7**	Oct-Feb	612	Nov	1962-
Queen Charlotte Sound							
Bella Coola River	08FB007	3730	**93.9**	June-Aug	703	Jan	1965-
Kitimat River	08FF001	1990	**131.0**	May-June	2820	Sept-Oct	1964-
Kemano River	08FE003	583	**44.9**	June-July	803	Sept-Oct	1971-
Nascall River	08FC002	383	**67.0**	June,Oct-Nov	886	Oct	1923-1952
Salloomt River	08FB004	161	**8.8**	May-June	141	Dec	1965-
Wannock River	08FA002	3940	**330.0**	June-Aug	2720	Jan	1927-
Dean River	08FC001	7850	**134.0**	May-June	872	May	1923-1932
Queen Charlotte Strait / Johnstone Strait							
(Mainland)							
Homathko River	08GD004	5720	**284.0**	June-Aug	2660	Sept-Oct	1957-
Klinaklini River	08GE002	5780	**293.0**	June-Aug	1830	Sept	1976-
(East Side Vancouver Island)							
Campbell River	08HD003	1460	**100.0**	Nov-Feb	739	Nov	1949-
Salmon River	08HD006	1200	**63.2**	Oct-Feb	1610	Jan	1956-
Kokish River	08HF001	290	**17.9**	Oct-Feb	334	Feb	1927-1941
Nimpkish River	08HF005	787	**59.2**	Oct-Feb	763	Apr	1990-
Reference							
Fraser River	08MH126	23200	**3660.0**	May-July	13700	Jun	1965-

Localized freshwater discharge often results in two-layer estuarine flow, whereby the surface outflow of less dense water is accompanied by a compensatory landward flow of more saline oceanic water at depth. This occurs in BC's fjords and estuaries and is described further in section 6.0. However, estuarine-type circulation can also occur on a larger scale and is thought to be a significant driver of water mass movements in PNCIMA waters. In Johnstone Strait this estuarine circulation is evident in the mean velocity and water properties structure. There is a mean seaward (westward) upper layer flow of about 0.2 m s^{-1}, strongest on the mainland side due to the Coriolis force, while the mean lower layer flow is landward (eastward) at about 0.1 m s^{-1}, strongest on the Vancouver Island side (Thomson 1981). As noted above, summer winds tend to push surface waters away from the coast, which brings deeper ocean water on to the shelf, especially along the deep troughs of Queen Charlotte Sound. This process is enhanced by the flow of buoyant fresh water out of the coastal inlets. In winter the runoff is pushed back against the coast by the wind conditions, restraining the estuarine flow. Thus, the intensity of estuarine flow over the shelf varies with the amount of runoff and the atmospheric forcing conditions.

2.8. Mean or Residual Currents

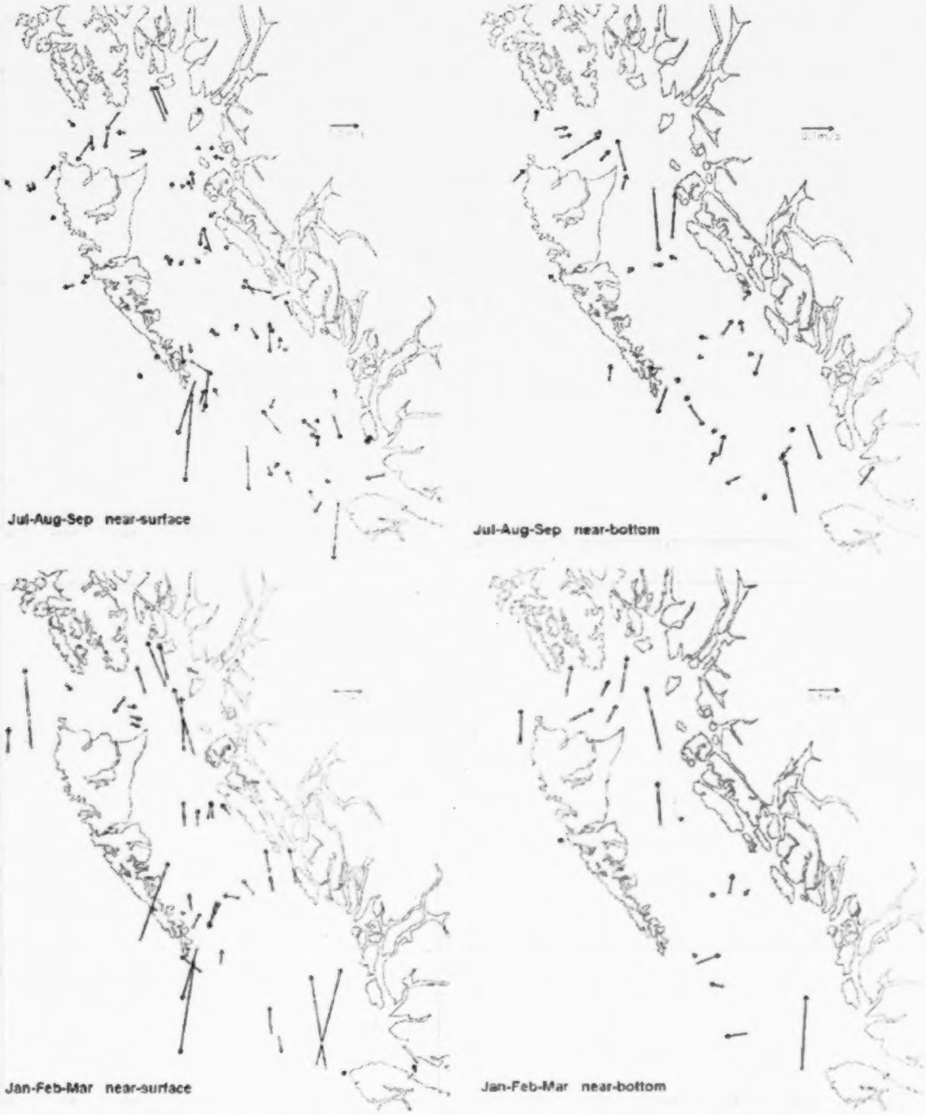
Mean or residual currents are the net currents when averaged over a long enough time period such that tidal and other short-term variability is removed.

Time-series records of current data collected by Fisheries and Oceans Canada (IOS) between 1977 and 1995 have been processed to produce vector plots of average currents near-surface and near-bottom for winter (Jan-Mar) and summer (Jul-Sep) (Crawford 2001; Cretney *et al.* 2002).

The average **summer** current vectors (upper two frames of Figure C.9) show variable currents within Queen Charlotte Sound, due to the weaker more variable winds during summer. There is little net transport through Hecate Strait. However, there are strong outflow currents near Cape St. James and Cape Scott which are thought to be driven by the summer winds from the northwest.

There are features not evident in Figure C.9 because current meters have not been placed in these regions (Thomson *et al.* 1989; Crawford *et al.* 1995). These features have been noted in drifter tracks and can be seen in the satellite photos in the next section.

During **winter** the winds shift to southerly and intensify. As a result there is a general northward drift throughout most of the area, with mean speeds of 0.2-0.6 m s^{-1}. However, the high-speed southward outflow persists near Cape St. James, contributing to the formation of the Haida Eddies (Crawford *et al.* 2002a). This outflow is thought to be the result of the inability of the narrow and shallow northern end of Hecate Strait to accommodate the volume of water flowing into Hecate Strait from the south (Hannah and Crawford 1996).



Jul-Aug-Sep near-surface

Jul-Aug-Sep near-bottom

Jan-Feb-Mar near-surface

Jan-Feb-Mar near-bottom

Figure C.9 Average currents in summer (upper) & winter (lower), based on 1977-1995 data collected by the Institute of Ocean Sciences. Near-surface (left): within 50 m of surface; near-bottom (right): within 20 m of bottom (from Cretney *et al.* 2002).

3.0 A SYNOPSIS OF KEY SEASONAL CURRENTS AND CIRCULATION

Satellite-acquired images of sea surface temperature (SST) in Figure C.10 and C.11 provide a synoptic "snap-shot" of the surface water temperatures. These in turn help illustrate the physical oceanographic processes that are occurring. The features identified on the images are believed to be recurring features as they have been seen on numerous satellite images, or have also been seen using drifter tracks or current meters.

The following discussion of the features apparent in the SST images is largely based on Crawford (2001), Cretney *et al.* (2002), and Crawford (2005). Because the sensors on satellites cannot see through clouds, images are presented for cloud free days, which usually correspond to northerly winds in summer and outflow winds in winter. Thus upwelled waters will be more pronounced than normal in summer and waters along the eastern shores will be colder in winter.

3.1. Summer (Figure C.10)

The winds over the BC coast during summer are relatively weak, but are predominantly from the northwest, resulting in a general southward flow of marine waters through this area. However, wind reversals often result in current reversals. A thermocline develops in spring/summer due to surface heating, freshwater runoff, and reduced wind mixing. The resulting warm surface layer is generally 10-20 m thick.

The freshwater runoff also tends to contain sediments allowing it to absorb light and heat, producing plumes of warm waters coming from Chatham Sound (Nass River) and the Skeena River estuary [1], and from some of the mainland inlets especially Rivers Inlet [7]. The outflow from the Skeena and Nass flows north and then west out of Dixon Entrance. Some Skeena River water likely exits Chatham Sound through Brown Passage and Edye Pass

When northwesterly winds are strong, cooler waters can occur on the western side of land masses. This can be seen by the southern Alaskan islands [2], the Queen Charlotte Islands [3], northern Vancouver Island [8] and along the eastern side of Queen Charlotte Sound and southern Hecate Strait [5]. The cool waters north of the Queen Charlotte Islands [2] are pulled in along the southern side of Dixon Entrance by the Rose Spit Eddy. Waters originating north of Aristazabal Island (the 'Aristazabal Island Plume' [5]), pass south of North Bank (Crawford *et al.* 1995; Crawford 2001) becoming part of the clockwise surface flow around this bank [A]. Tidally mixed cold waters over Cook Bank [8] are pushed westward where some portion of them joins the southward flowing shelf break current [12].

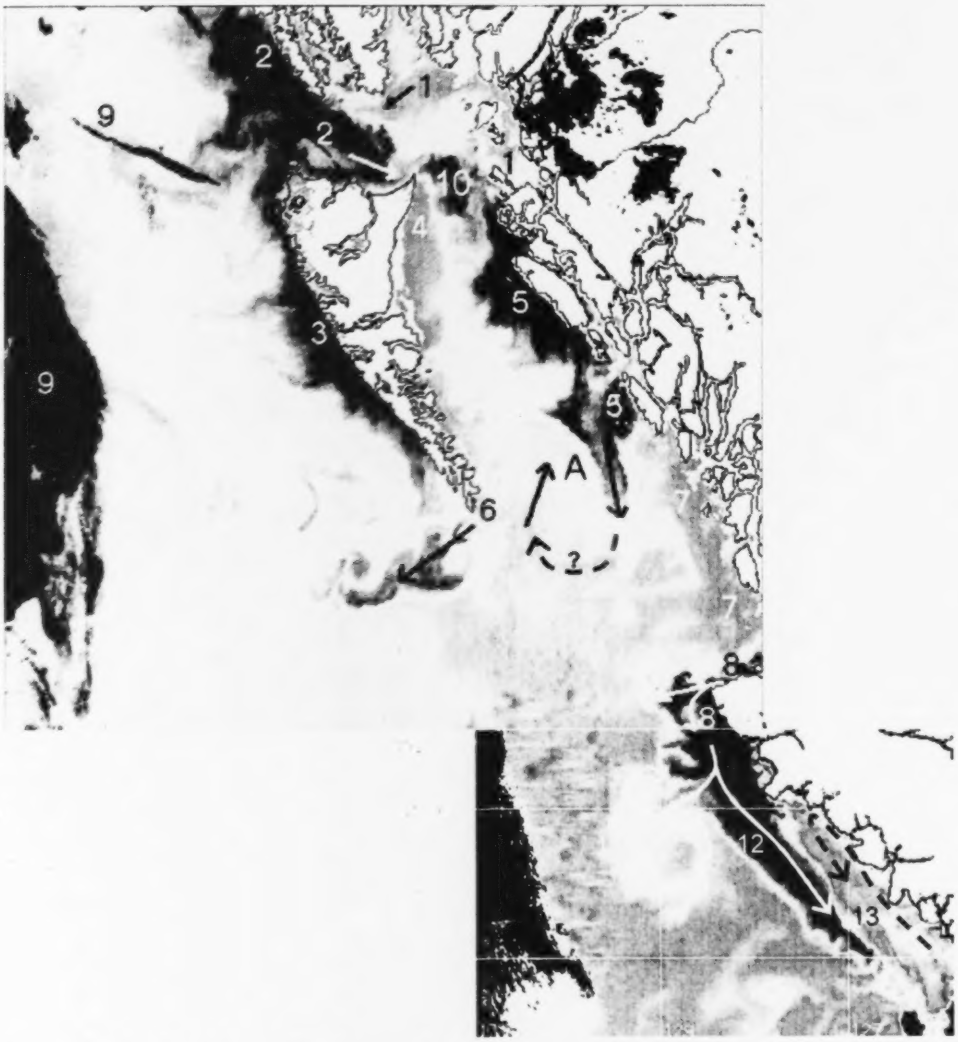


Figure C.10 NOAA satellite image of sea surface temperature processed by Jim Gower and John Wallace of Fisheries and Oceans Canada. The lower portion was collected 23 July 1994 at about midnight PDT, the upper portion was collected 24 July 1994 at about 0600 PDT; cold water (~10°C) is represented by the colour blue and warm (~16°C) by red. Arrows denote surface currents. The numbers in square brackets [n] refer to features identified on the SST images. Black areas are clouds.

During summer there is a strong narrow outflow current near Cape St. James [6]. Drifters passing close to the cape reached speeds of 2.5 m s^{-1}, reversing only occasionally during flood currents and unaffected by wind direction (Crawford *et al.* 1995). Many of the drifters tracked in Queen Charlotte Sound and southern Hecate Strait by DFO headed towards the deep ocean by passing close to Cape St. James. This raised concerns regarding transport of pollutants (Cretney *et al.* 2002) because the southern end of the Queen Charlotte Islands is part of the proposed Gwaii Haanas National Marine Conservation Area Reserve (http://parkscan.harbour.com/gwaii/marineconservation.htm).

North Bank [A] lies between Moresby Trough and Mitchell's Trough. The waters over North Bank are persistently warmer than the surrounding waters during late summer (Jardine *et al.* 1993). There are apparently two reasons for this. First, the bank is too deep for tidal mixing to cool down the surface waters, and second, cold water moves shoreward up Moresby Trough and along the northeast side of the bank, while the cold Aristazabal Island Plume flows seaward on the east and south sides of the bank [5] (Crawford *et al.* 1995) with both flows avoiding the Bank. Drifters over North Bank [A] exhibit semi-diurnal tidal excursions of about 10 km, but they tend to drift slowly clockwise around the Bank during summer (Crawford *et al.* 1988; 1995; Hannah *et al.* 1991; Crawford 1997).

Two features of note at the north end of Hecate Strait are a patch of cold water resulting from strong tidal mixing near the point of Rose Spit [10]. Beside this and down the Eastern side of the Queen Charlotte Islands are very warm surface waters unrelated to freshwater outflow. This area overlies a large bank ([illegible] Dogfish Banks) with very shallow water that warms in summer.

The cooler waters over Cook Bank [8] are pushed westward during northeast winds (Crawford *et al.* 1985) where some portion of this flow joins the southward-flowing shelf-break current [12]. Jets of this water can be seen extending west, often forming single or paired eddies such as the 'hammerhead' feature seen at [11]. This jet may be a result of the physical barrier of the Brooks Peninsula. The Brooks Peninsula can also be a barrier to the northward flowing Vancouver Island Coastal Current [13] which sometimes is seen to turn back and join the shelf break current. Hence the choice of Brooks Peninsula for a southern boundary of PNCIMA.

3.2. Winter (Figure C.11)

During winter the winds increase in strength and switch to predominantly southeasterlies. The net water movement becomes northwestward into Queen Charlotte Sound and along Hecate Strait [2]. Coriolis force pushes these flows to the right, toward the mainland side, where it encounters outflowing freshwater runoff [4].

The strong outflow in summer close to Cape St. James persists [3] and even strengthens when the winds shift to southeasterly in winter. As in summer, the outflow very near the Cape is believed to be partly due to a steady residual tidal current (Crawford *et al.* 1995; Foreman *et al.* 1993; Thomson and Wilson 1987), but in winter the outflow is augmented by a southerly flow along the northwest side of Moresby Trough [9]. This flow is believed to be due to a pressure gradient set up by the southeasterly winter winds (Hannah and Crawford 1996) that pushes back some of the flow heading north up Hecate Strait. This pressure gradient forces water southwards along the western side of Hecate Strait and supplies the outflow current past Cape St. James (Crawford *et al.* 2002a). This strong outflow current is thought to be the source of Haida Eddies [1] described in more detail below.

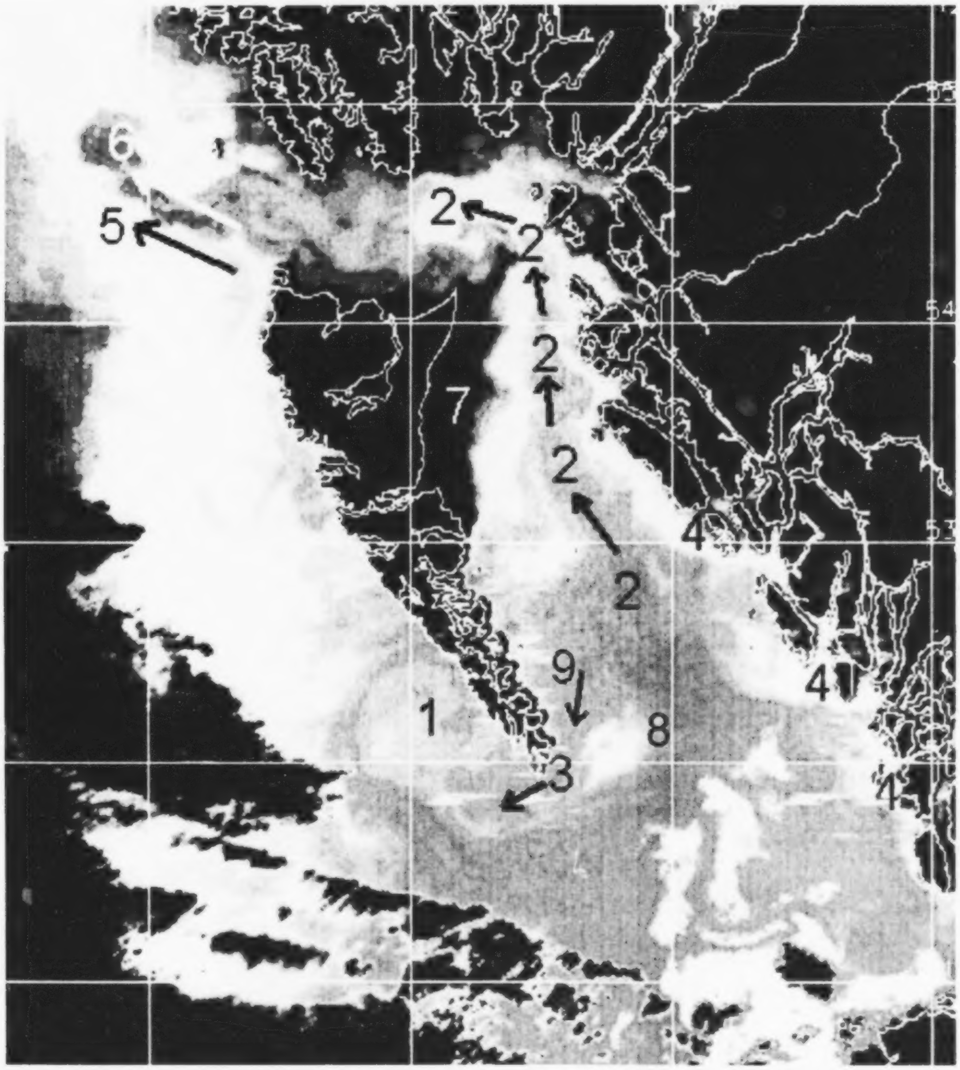


Figure C.11 NOAA satellite image processed by Jim Gower and John Wallace of Fisheries and Oceans Canada. The winter image is from 26 December 1996 at about 2100 PST: temperatures range from 4°C (blue) to 8°C (white). The numbers in square brackets refer to features identified on the SST images. Black areas are clouds.

During winter, the flow around the northern end of North Bank switches to westerly (Crawford 1997) and it is thought that a cyclonic (counterclockwise) eddy might form over the bank [8]. It has been suggested that this eddy provides a winter haven for some Pacific cod larvae, preventing them from being washed up Hecate Strait and out of Dixon Entrance with the main flow [2] (Crawford *et al.* 1990).

Currents on the west side of the Queen Charlotte Islands flow northwards, though they can be deflected offshore [5] if the outflow from Dixon Entrance is strong [6]. It is worth noting that the main northward flowing surface waters are relatively warm [2,5] compared to the cooler and fresher near-shore waters [4]. The shallow waters over Dogfish Banks are also cooler than the waters from the south [7]. Tidal and wind mixing are strong here but clearly these waters do not exchange much with the warm flow on the eastern side of Hecate Strait [2]. This warmer northward flow [2] continues into Dixon Entrance, diminished somewhat at Rose Spit by mixing in these shallows. Its westward progress through Dixon Entrance is possibly stopped by the Rose Spit Eddy.

3.3. Haida Eddies (Figure C.11)

Every winter the outflow currents past Cape St. James form one or two large Haida Eddies. They are similar to those that form further north near Sitka Alaska (Tabata 1982). Within weeks to months of formation they drift westward into deeper waters of the Pacific Ocean. Haida Eddies are characterized as: anti-cyclonic (rotate clockwise), baroclinic, 200 km or more in diameter, warmer than the surrounding waters below the top 100 m, normally less saline than surrounding waters, and have a sea surface height anomaly of up to 0.5 m (Crawford and Whitney 1999; Crawford *et al.* 2002a). A series of papers on this eddy were published in April 2005 in a special issue of Deep-Sea Research, Part II, with data for this project available on line at http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/default_e.htm.

Haida Eddies are believed to form when the outflow current interacts with Cape St. James (Crawford *et al.* 2002a). The necessary rotation of currents may result from buoyancy forces as the outflow current passes along the eastern side of the southern Queen Charlotte Islands (DiLorenzo *et al.* 2005).

The westward drift of the eddies results in the offshore transport of large amounts of coastal water (Whitney and Robert 2002). Nutrients, plankton, larval fish and invertebrates are transported offshore with these coastal waters (DFO 2002; Mackas and Galbraith 2002). This process also moves heat and fresh water from the BC coast into the Gulf of Alaska (Crawford 2005).

Haida Eddies are larger during winters of strong El Niño events with high sea levels along the BC central coast. The 1998 eddy was the strongest ever observed, estimated to contain approximately 5,000 km^3 of coastal water from PNCIMA, which is about the entire volume of Queen Charlotte Sound and Hecate Strait combined (DFO 2002; Whitney and Robert 2002).

4.0 SEA LEVEL VARIATIONS

Changes in sea level along the BC coast are primarily due to the tides; however, there are other episodic and seasonal factors that can also significantly affect the water levels.

4.1. Tides

The gravitational pull of the sun and the moon on the ocean waters causes the periodic rise and fall in water level known as the tide. This astronomical tide accounts for most of the variations in sea level along the central BC coast. The mean tidal range (low to high) for the BC central coast region is about 3.6 m, with large ranges up to 6 m (Canadian Hydrographic Service 2002).

The tides along the BC central coast are classified as mixed, mainly semi-diurnal (denoted as M_2, two highs and two lows every 24.75 hours, but successive highs or lows are of unequal height). There is a spring-neap cycle of about 14 days as the sun and moon work together at full and new moons. Tidal ranges during spring tides are about twice those that occur during the weaker neap tides. For example the spring tide range at Bella Bella is almost 5 m, reducing to about 2 m during neap tides (Figure C.12). Tidal patterns are similar for other parts of the PNCIMA region (Figure C.13).

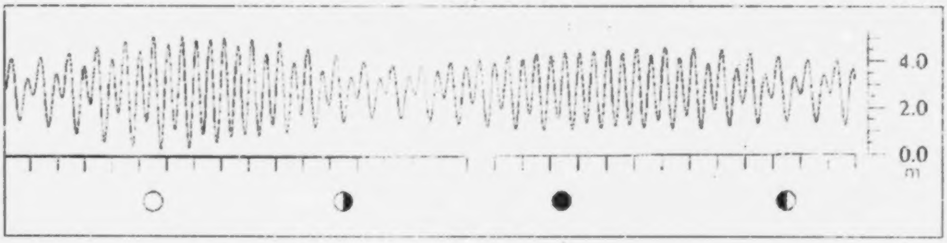


Figure C.12 Monthly tidal cycle for Bella Bella. The x-axis is time with increments of one day. Times of new (●) and full (○) moon are indicated on the x-axis.

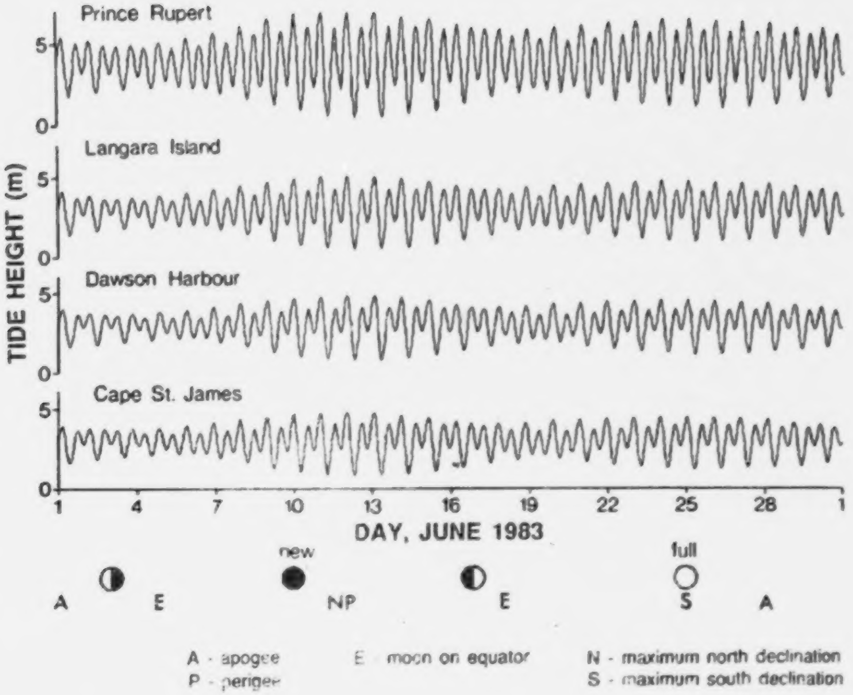


Figure C.13 Monthly tidal cycle for Prince Rupert and three locations on the Queen Charlotte Islands: Langara Island at the north end, Cape St. James at the south end and Dawson Harbour on the middle of the western coast (from Thomson 1989).

After entering Queen Charlotte Sound, the tide floods northward up Hecate Strait, meeting (in northern Hecate Strait) the tide that entered through Dixon Entrance (Figure C.14). The tidal range increases as the depth decreases and because of positive interference with the wave from Dixon Entrance. Thus, the tidal ranges are largest in the area that the two components meet. As the tide moves north through Hecate Strait, the mean tide range increases from about 3 m at the entrance to Queen Charlotte Sound to about 5 m midway up Hecate Strait. Part of the tide reflects back from northern Hecate Strait, resulting in what investigators think may be a standing wave (Foreman *et al.* 1993; Thomson 1989).

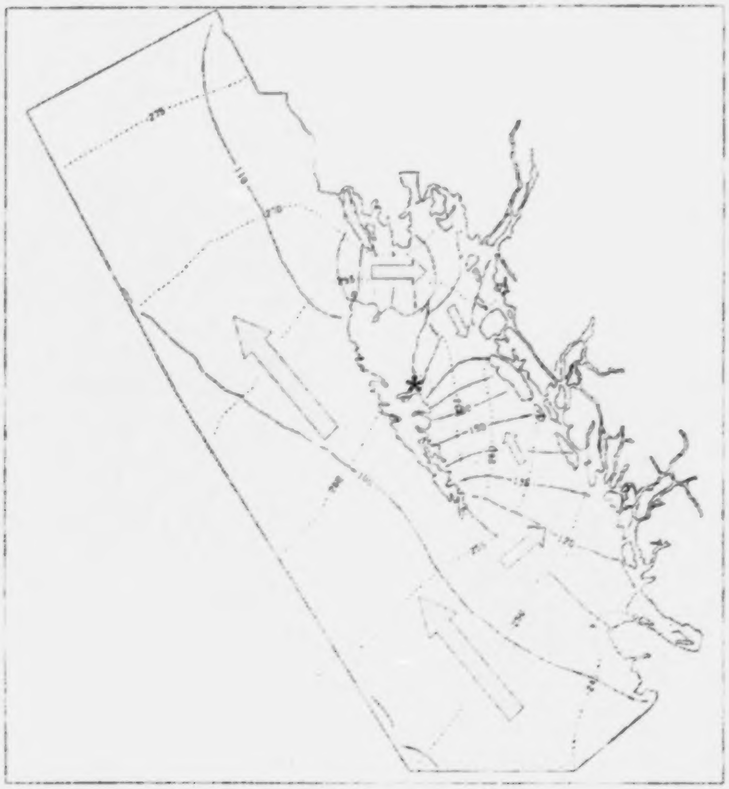


Figure C.14 Path of the M_2 (mixed, mainly semidiurnal) tidal peak through PNCIMA (adapted from Foreman *et al.* 1993). Dashed contours denote Greenwich phase lag in degrees and solid contours show height in cm. Star denotes region of highest tide in the model. Arrows show the direction of tidal crest on a flood tide.

The tide also floods south from Queen Charlotte Sound into Queen Charlotte Strait. Available information from short-term (one month or more) temporary tide stations in the Broughton Archipelago indicates tidal ranges up to 6 m. Further south in Johnstone Strait and Discovery Passage the tide loses energy in the narrow passages, and the range decreases as it transits Johnstone Strait (Thomson 1981). Here the mean tide range is approximately 3 m. The tide is mostly semi-diurnal at the western end of Johnstone Strait, becoming more mixed in Johnstone Strait/Discovery Passage. At Campbell River, the southern end of our study area, the tide is mainly diurnal for about 12 days of each month.

4.2. Waves

This region experiences large waves primarily arising from the passage of storms traveling eastward over the Northeast Pacific Ocean. In particular, the rapidly deepening, fast moving extra-tropical cyclones represent a significant marine hazard, as was the case in the deaths of five fishermen and the sinking of several fishing vessels during the storm of October 11-12, 1984 (LeBlond 1985).

Queen Charlotte Sound and southern Hecate Strait are open to large fetches, particularly from the southwest, and can receive long-period swells (16-22 second period) although average wave periods are generally about 5-10 seconds for most months (Thomson 1989). During late autumn and winter, wave heights in excess of 3.5 m occur 20-30% of the time offshore, reducing to 10% along the coast (Thomson 1989). Periods of large waves recur every 2 to 5 days during winter, consistent with the interval between the passages of frontal systems. Storm-force winds (gusting to 90-100 knots), accompanied by 8-10 m high waves, occur several times each winter (Environment Canada 1992). The onset of autumn storms generally occurs in late September or October.

An extensive study of waves resulting from severe storms between 1957 and 1989 (Canadian Climate Centre 1992) indicated that significant wave heights (the average of the largest one-third of all waves present) of the large waves of 10 m or more are almost always associated with strong southwesterly winds. Statistical extrapolation methods were used to estimate the largest significant and maximum wave height expected over a 100-year period. The results for the 100-year return period wave were values of significant wave heights of 13.2 m and maximum wave heights of nearly 25 m in Queen Charlotte Sound. Such extreme wave conditions have been reported at least twice, once from an offshore drilling off Cape St. James during October 1968 where maximum wave heights reached 29 m (James 1969), and during December 1993 in the entrance to Queen Charlotte Sound with a buoy-based measurement of 30.8 m (Gower and Jones 1994). While there is some debate as to the validity of the 30.8 m value (Thomas 1995), there is no question that very large ocean waves, >20 m maximum height, can occur in the open exposed waters of the BC coast.

In the Canadian Climate Centre study, the effects of shallow waters and wave-current inter-actions were not explicitly dealt with. Storm-generated waves can be augmented in the shelf and coastal waters by opposing tidal currents and the effects of shallow banks. Masson (1996) shows that the strong tidal currents around Cape St. James can significantly alter the wave properties in these coastal waters and may account for the increased severity of ocean waves there. Like the Cape St. James area, strong currents near Cape Scott (up to 2.5 m s^{-1}) can steepen a westerly swell, so this area can also be particularly dangerous to mariners.

Southern Hecate Strait receives little shelter from the main storm systems and the wave conditions can be as severe as in Queen Charlotte Sound, although in general waves are larger at the entrance to Queen Charlotte Sound than in southern Hecate Strait. Large waves (5-10 m) can occur in some of the central coast sounds and channels, particularly if they align with the prevailing wind directions. While Queen Charlotte Strait has limited fetch, remnants of Pacific swells penetrate the Strait and waves of 3-4 meters can be expected (Thomson 1981).

The coastal waterways, including the inlets and fjords, are generally more sheltered with weaker winds and reduced fetch. However, strong winds, particularly when combined with an opposing tide, can generate steep, choppy wave conditions of 1-2 m height. For example on the outer edge of the Broughton Archipelago, summer afternoon winds can rise to gale-force westerlies and seas can become dangerous during ebb tide. Outflow winds during fall and winter can produce rough seas even in the inlets, up to 3 m in Knight and Rivers inlets (Province of British Columbia 2001), and almost 2 m in Quatsino Sound (Ricker *et al.* 1989). The Nahwitti Bar can be treacherous in any season.

The wind and wave climate itself is subject to change over time periods of decades and longer. Major changes in the winter storm climate occurred from 1949 to 1998, with an increase in the number of intense storms and a shift of the storm tracks to the south (Graham *et al.* 2002). These changes are estimated to have resulted in an increase, over those 50 years, of the yearly 95th percentile wave value by as much as 2 m off California, but only 0.3 m off the BC central coast (Graham and Diaz 2002).

Dixon Entrance tends to exhibit wave heights intermediate between the more exposed Queen Charlotte Sound and the more protected Hecate Strait. It is well protected from waves coming from the south, but swell coming in from the west enters and can be amplified or focused by bottom topography such as Learmonth Bank (Thomson 1981).

4.3. Inverted Barometer Effect and Storm Surges

The inverted barometer effect (higher atmospheric pressure depresses the sea surface; low atmospheric pressure raises the sea surface) can change the water level about 1 cm for every 100 Pascal change in air pressure (100 Pascals = 1 millibar). This is particularly noticeable during winter with sea level changes on the order of 30 cm common (Crawford 1980).

Storm surges are caused by wind stress acting on the water surface causing a direct set-up of the sea level. Storm surges have the greatest effect in shallow water and low-lying coastal areas such as the Mackenzie Delta in the Yukon and in the Bay of Fundy. This is generally not the case along the BC coast. Surges on the order of 20 cm associated with strong southeast winds have been observed (Jamieson *et al.* 1982; Wickett 1973), and intense offshore extra-tropical cyclones can generate a larger surge response. Such an event occurred on December 16-18, 1982 (Murty *et al.* 1995) in which surge heights as large as 90 cm were experienced on Vancouver Island, with smaller effects observed further north at Bella Bella. The combined impact of surges and wave damage is greatest along the northeast shore of Graham Island. This lowland region has British Columbia's most rapidly eroding shore.

4.4. Tsunamis

Tsunamis are ocean waves formed by sudden movement of the land. They can be extremely destructive and endanger human lives where they strike populated coastlines. Tsunamis can form in four ways. Generally they are the result of a submarine earthquake, less commonly as a result of an underwater landslide or a surface landslide that enters the water, infrequently by submarine volcanic eruptions and very rarely as a result of a meteor impact in the ocean (NOAA 2005). The latter two are rare and the coast of BC is no more susceptible to them than other coastal areas. However, the BC coast is susceptible to submarine earthquakes and landslides, and their tsunamis have been recorded along this coast (Rabinovich *et al.* 2003).

Earthquakes can generate tsunamis by causing abrupt shifts in the seafloor that displace large volumes of seawater (Murty 1977). Tsunamis are long-period waves (15-90 minutes) that travel rapidly from the source. The extent of flooding and damage to the affected coastal areas depends on factors such as the bathymetry and distance from the source. The March 1964 earthquake that caused major damage to Port Alberni (Thomson 1981; Wigen and White 1964) also penetrated the central BC coast and resulted in high water levels at Bella Bella and damage at Ocean Falls (Spaeth and Berkman 1967). Funnelling and resonance in an inlet can increase wave heights toward the head of the inlet.

A large earthquake along the Cascadia Subduction Zone is believed to have caused a giant tsunami about 300 years ago that devastated the southern BC outer coast. The timing is based on historical and sediment records (Lopez and Bobrowsky 2001). Recurrence intervals for mega-thrust earthquakes are estimated to be about 300-500 years (Atwater and Hemphill-Haley 1997; Hyndman *et al.* 1999). Tsunamis from such earthquakes will reach PNCIMA and their expected heights through PNCIMA are in need of study. Cherniawsky *et al.* (2007) have simulated this type of tsunami for southern BC, but not for PNCIMA.

On a smaller geographic scale, localized slumping and avalanches, due to the steep terrain and high rainfall, can cause tsunami-type waves in the coastal areas, again as a result of displacing a large volume of water. A submarine slide in Kitimat Arm in April 1975 resulted in a wave estimated at 8.2 m in height (Golder Assoc. 1975; Murty and Brown 1979). An underwater landslide November 1994 in Skagway Harbor (southeastern Alaska) generated a tsunami that was estimated to be 5-6 m high in the harbour, increasing to 9-11 m as it hit the far shore (Kulikov *et al.* 1996). Known submarine landslides and related tsunamis for the coasts of Alaska, British Columbia, and Washington were recently summarized in Rabinovich *et al.* (2003). This kind of tsunami risk can be evaluated by analysis of the surface and submarine slope stability along the BC coast. This work has been done for some areas. Cousins Inlet is known to be susceptible, and Moses Inlet was singled out in a report by the BC Land Use Coordination Office (Province of British Columbia 1998), stating that "a 9.3 m tsunami wave could reach the head of Moses Inlet". Avalanche chutes lead into many of the northern inlets (*e.g.*, Princess Royal Channel). Many of the river deltas in Dean Channel are of suspect stability, and some banks show evidence of instability (Cretney *et al.* 2002). Rabinovich *et al.* (2003) use a model approach to assess the tsunami risk in two areas of the Strait of Georgia.

4.5. Seasonal Effects on Water Level

During winter, the northerly movement of water due to the prevailing southerly winds results in an average 10-20 cm rise in sea level along the central BC coast (black line, Figure C.15). The opposite happens in summer with a corresponding, but smaller, drop in the coastal sea level (Thomson and Crawford 1997).

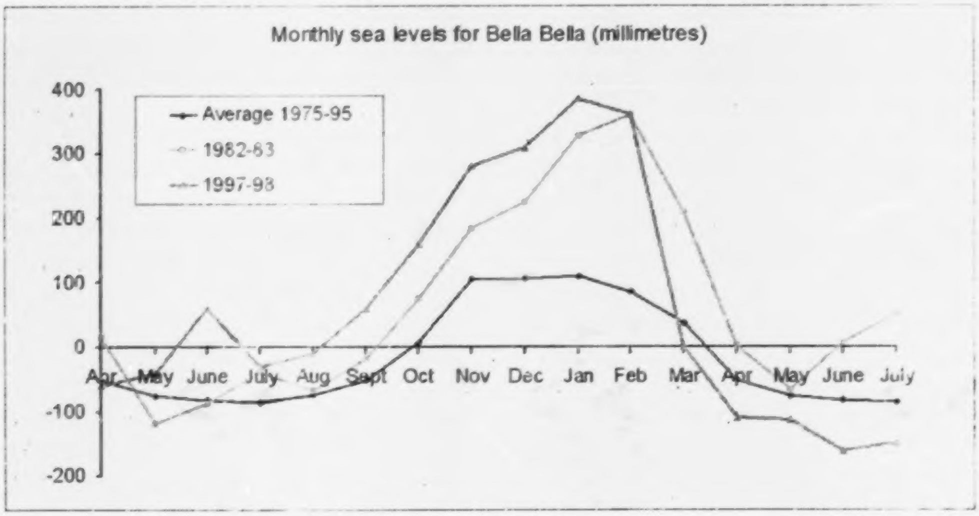


Figure C.15 Monthly sea levels (mm) at Bella Bella; 20-year average (1975-95), and during the 1982-83 and 1997-98 El Niños (courtesy of W. Crawford).

The El Niño-Southern Oscillation (ENSO) cycle can cause further fluctuations in water levels through several seasons. During an intense El Niño the northerly surge of warm water reaches Queen Charlotte Sound, causing water levels to remain about 35 to 40 cm above normal winter levels for a month or more (red and grey lines, Figure C.15).

4.6. Long-Term Sea Level Changes

Long term changes in sea level resulting from the factors described above, as well as global climate change, are evident from analyses of long-duration tidal station records. Sea level at Prince Rupert has been rising at a rate of 11-12 cm per century over the past 95 years (BC MWLAP 2002; DFO 2006). The Intergovernmental Panel for Climate Change (2007) estimates that sea level will rise by 0.2 to 0.6 metres in 2090 to 2099 relative to 1980 to 1999. Most regions of the ocean will be within 5 cm or so of this level by 2090 to 2099. The range of 0.2 to 0.6 metres is due to different scenarios and models of climate change. The range of uncertainty is even bigger if ice flows from Greenland or Antarctica melt at rates different from the average of 1993 to 2003. Sea level will continue to rise after 2099, at similar or higher rates. An equilibrium level with future climate warming will be many metres (or tens of metres) above present sea levels.

5.0 WATER PROPERTIES

The properties of PNCIMA waters are variable, both spatially and temporally, being influenced by oceanic as well as coastal processes. Offshore surface waters are more saline and generally cooler than those near shore. Coastal waters are subject to runoff, bathymetric influences and topographically directed winds. Strong tidal currents in constricted passes cause intense mixing, increasing the salinity and nutrients in the surface waters, but decreasing the temperature and dissolved oxygen.

Coastal inlet waters are influenced by the amount of runoff and exchange with the offshore waters (discussed further in section 6.0). Shallow sills are commonly present near the mouth of BC inlets, restrict the exchange and flushing of basin waters which can result in oxygen depletion. Queen Charlotte Strait is restricted by a 140 m deep sill at the western entrance, while the central strait reaches depths of 400 m.

The water properties of the PNCIMA area vary seasonally, with winter and summer extremes. The associated large-scale wind shifts between winter and summer, and the resulting changes in overall current patterns, control the make-up of the water masses. Southerly winds dominate in winter, causing a rise in sea level through PNCIMA, and a thickening of the surface layer, as noted earlier. Conversely, in summer, relaxation of downwelling winds produces a surface offshore flow and a deep onshore flow of colder, more saline water onto the continental shelf and into most inlet basins. As a result, the bottom waters of Queen Charlotte Sound are warmer in winter than in summer (Dodimead 1980).

Figure C.16 shows the seasonal variability of near-surface temperature and salinity for Cape St. James at the southern tip of the Queen Charlotte Islands, and at McInnes Island located on the eastern side of Queen Charlotte Sound. At Cape St. James the surface water temperatures exhibit a seasonal cycle, warmer in summer (~13°C) than in winter (~7°C). Salinities are about 32-32.5, and are slightly lower in the late summer and early autumn. (Salinity was traditionally reported in parts per thousand by weight. Since 1978, when it was redefined, it has been reported without units, but with numerical values close to the concentration in parts per thousand). At McInnes Island, along the eastern side of Queen Charlotte Sound, the seasonal temperature cycle is similar to that at Cape St. James, however the salinities are more varied with higher values in the spring (~30.7) and lower values in the fall (~29.5). The standard deviation of the salinity values is large, indicating high variability in near shore salinities due to runoff, upwelling and other processes.

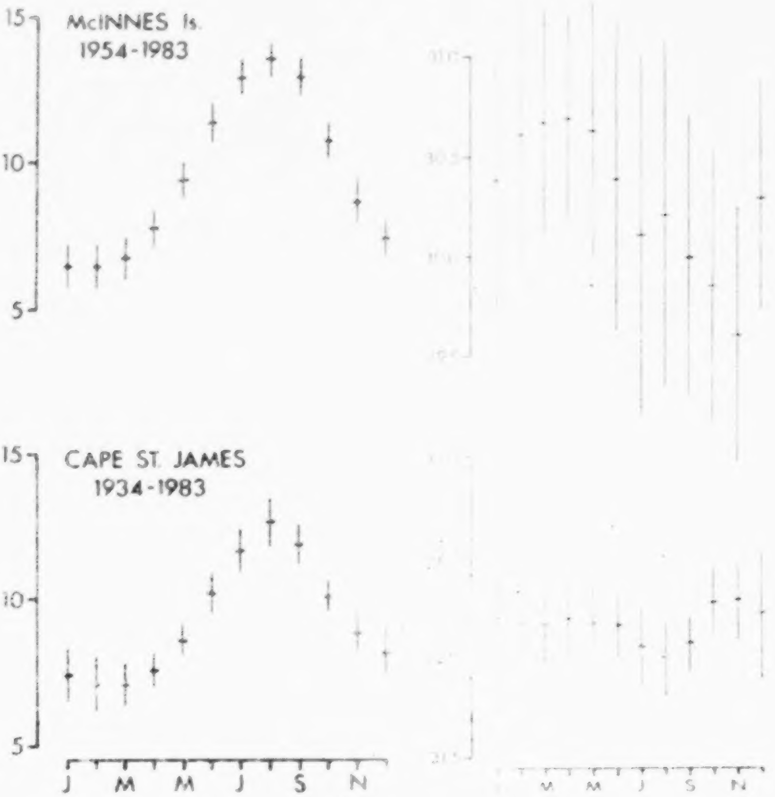


Figure C.16 Monthly-averaged sea surface temperatures in °C (left) and salinities (right) for Cape St. James and McInnes Island; (Thomson 1989 updated from Dodimead 1980).

Year-to-year changes also occur, such as those due to the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation cycles. During strong El Niño years, warm waters flow as far north as Alaska, raising surface water temperatures along the BC coast as much as 2°C or more. This is discussed in more detail in section 5.7 on long-term variability.

5.1. Temperature

Near-surface water temperatures are, on average, about 9-15°C during summer, and 6-9°C in winter. Figure C.17 illustrates the average water temperatures near-surface and near-bottom, for summer and winter (Crawford 2001). The panels represent long-term average conditions. Data from individual cruises during 1954-1962 are described by (Dodimead 1980); observations during 1982-1995 are available in Crawford (2001).

Note the reduced surface water temperatures (9-12°C) in summer, as displayed in Figure C.17, due to strong tidal mixing around Cape Scott, Cape St. James, and especially in Queen Charlotte Strait, and Johnstone Strait. In 1990, southeast of Cape St. James, colder and more saline waters extended to almost 100 m depth (Crawford *et al.* 1995). Surface waters are also colder over Goose Island Bank during summer, again due to the mixing that occurs over this shallow bank. The waters along the central mainland coast are colder on average in summer than are the waters in mid-sound, due to discharge of rivers fed by snow melt, and possibly due to upwelling and tidal mixing.

Bottom water temperatures are depth-dependent with the deeper waters usually colder. During summer, water temperatures in the troughs and deep areas are 5-6°C on average, increasing to 7-9°C over the shallower banks. Transport of colder water from offshore helps suppress these deep-water temperatures. A similar pattern is evident in winter with bottom water temperatures over the banks averaging 8-9°C, decreasing to about 5-8°C in the deeper areas. Note that in deep troughs the bottom waters are warmer in winter. The average temperature of the bottom waters over the banks varies little from summer to winter.

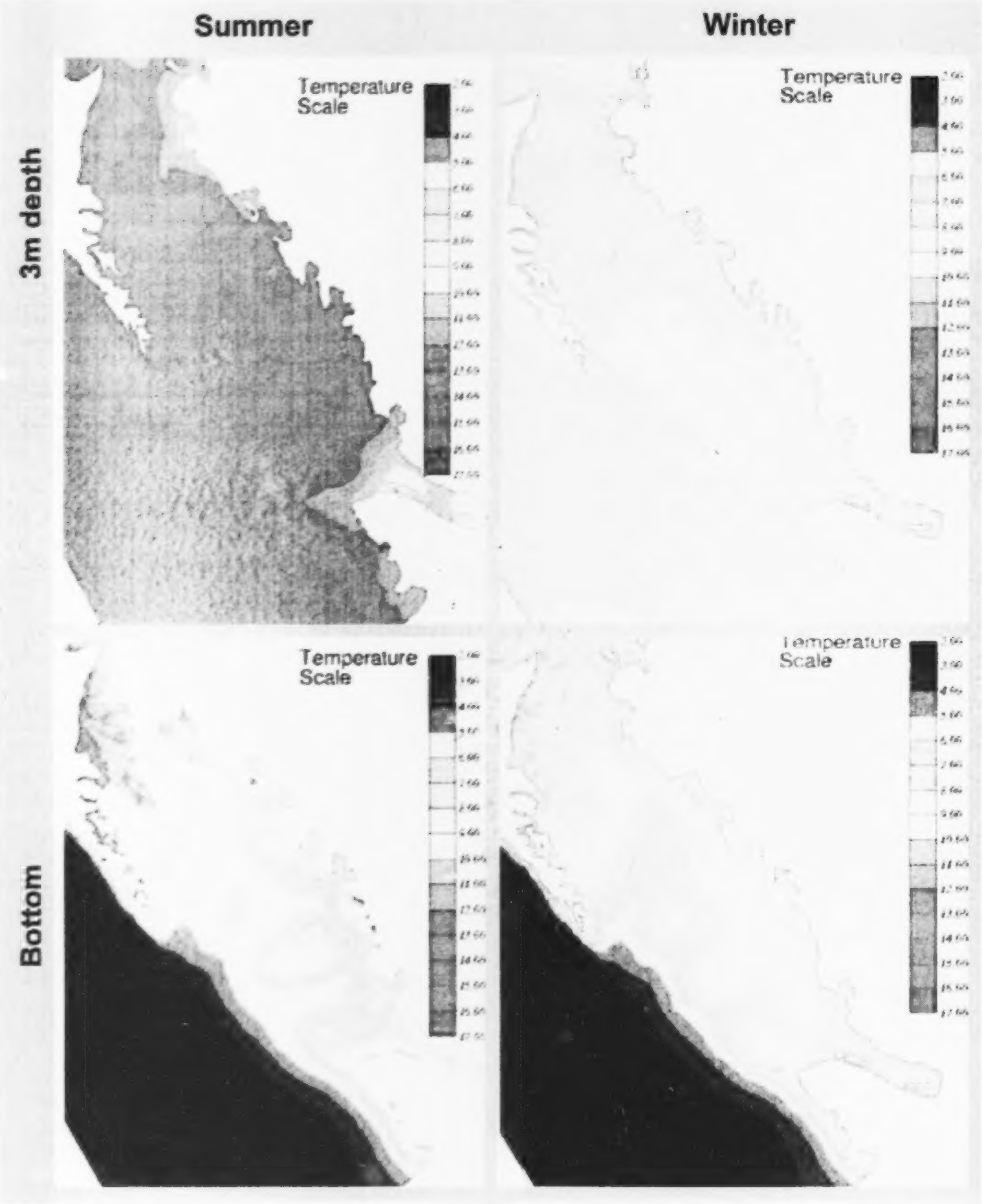

Summer
Winter
3m depth
Bottom
Temperature Scale
Temperature Scale
Temperature Scale
Temperature Scale

Figure C.17 Average water temperatures (°C). Upper: summer/winter near-surface; Lower: summer/winter near-bottom (from Crawford 2001).

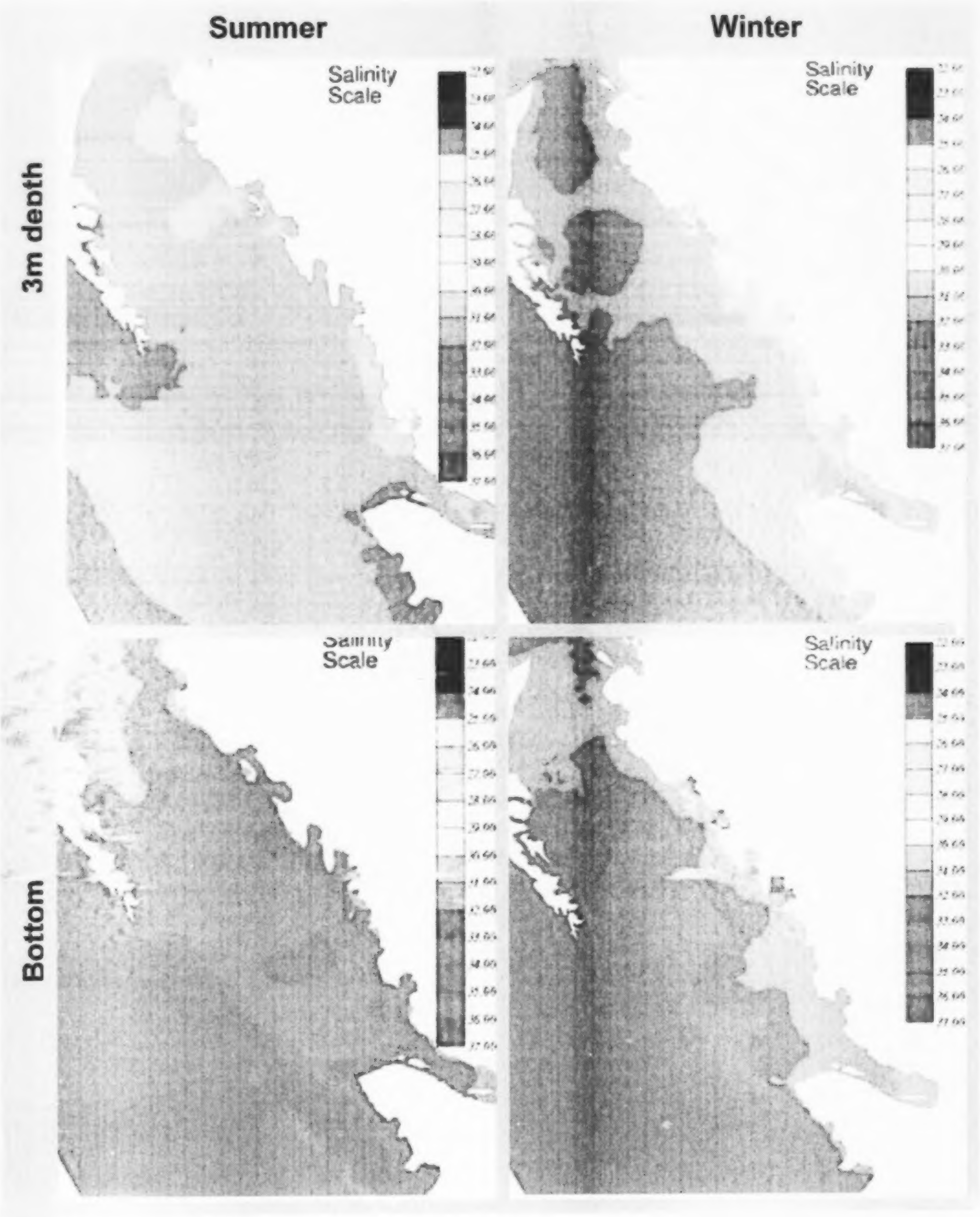

Summer
Winter
3m depth
Bottom
Salinity Scale
Salinity Scale
Salinity Scale
Salinity Scale

Figure C.18 Average of all available water salinities. Upper: summer/winter near-surface: Lower: summer/winter near-bottom (from Crawford 2001).

5.2. Salinity

As with the earlier plots of averaged temperatures, Fisheries and Oceans Canada has produced average salinity contour plots for near-surface and near-bottom, summer and winter conditions (Figure C.18).

Near-surface salinities are, on average, about 29-33 during both summer and winter. Fresher waters occur near the coast from runoff, and more saline waters occur offshore. The surface waters in central Queen Charlotte Sound during winter are more saline than those near its eastern shore, because the southerly winds tend to confine freshwater runoff close to the coast. The summer discharge of low salinity waters from Rivers Inlet/Hakai Passage and other inlets to the north is apparent even in this averaged plot. Higher surface salinities occur at the northern end of Vancouver Island (summer) and off Cape St. James (both summer & winter) due to strong tidal mixing. Near-surface salinities in Queen Charlotte Strait range from 31-33 throughout the year (lowest in winter; more saline at depth), and 30-32 in Johnstone Strait which has a slightly less saline upper layer (Thomson 1976).

Average near-bottom salinities in Queen Charlotte Sound vary from about 31 to 34 (lower half of figure). As with temperature, they exhibit a bathymetric influence. For example, the shallow near-bottom waters over Goose Island Bank are less saline than the deeper surrounding waters. In winter the bottom waters along the coast are less saline than further offshore due to wind-driven downwelling and mixing.

5.3. Dissolved Oxygen

Dissolved oxygen (DO) in seawater is essential for the survival of marine animals in the ocean. The tolerance of various marine organisms to oxygen concentration is dependent on their metabolic needs. Very active fish species such as salmon become stressed when seawater oxygen decreases below 70% saturation, whereas more senescent species (*e.g.*, sablefish) dwell in waters with less than 10% oxygen saturation. A low oxygen condition, termed hypoxia, affects the behaviour and development of many organisms when oxygen declines below ~1.4 ml l^{-1} in seawater (about 20% saturation; Gray *et al.* 2002). Hypoxia is common in the deeper waters of Queen Charlotte Sound and many inlets during summer, restricting the species that can inhabit these waters.

Oxygen is supplied to the ocean from the atmosphere and through photosynthesis; it is consumed by marine animals and bacteria. In the North Pacific, surface waters are near saturation levels, often exceeding saturation during phytoplankton blooms in spring and summer. However, strong stratification of this ocean realm restricts oxygen transport into deeper waters (unlike the North Atlantic and Arctic Oceans). In offshore waters, oxygen is below 10% saturation at a depth of 400 m. In coastal inlets, oxygen is occasionally completely utilized in basins with restricted circulation. Anoxia can be either an episodic or persistent condition in such inlets. In the PNCIMA region, anoxic conditions have been recorded in Frederick Sound (Seymour Inlet), Alison Sound (Belize Inlet), Roscoe Inlet, Spiller Inlet and the inner basin of Smith Inlet (Figure C.19). The best sampled of these, the inner basin of Smith Inlet, recorded anoxia in spring 1998 and 2004. During several other surveys between 2000 and 2005, traces of oxygen were present. Other inlets may have prolonged periods of anoxia brought about by the weak flushing of their basin waters. Frederick Sound basin waters were anoxic during recent surveys in 1998, 2000 and 2003, but not in 2002.

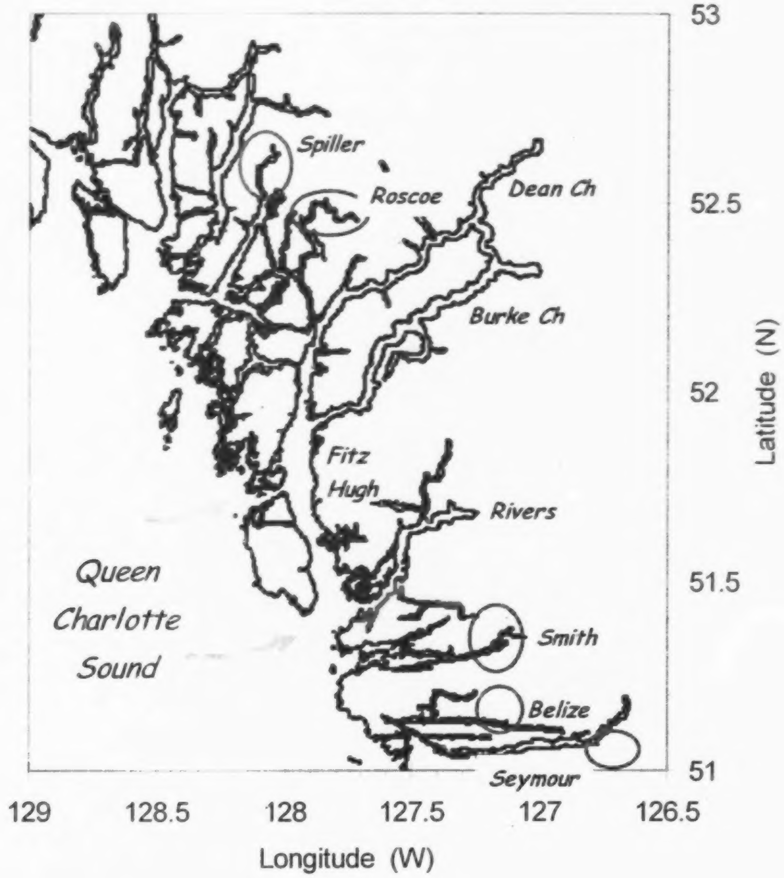

Spiller
Roscoe
Dean Ch
Burke Ch
Fitz Hugh
Rivers
Queen Charlotte Sound
Smith
Belize
Seymour
53
52.5
52
51.5
51
Latitude (N)
129
128.5
128
127.5
127
126.5
Longitude (W)

Figure C.19 Central BC coast, showing coastal inlets in which anoxic conditions (blue circles) have been found. Small inlets joined to Belize and Seymour inlets are circled but not labelled on this map. Gray arrows denote troughs through which dense waters enter the Rivers Inlet, Fitz Hugh Sound complex of inlets and channels in summer.

Throughout PNCIMA, low oxygen regions can be identified in summer (Figure C.20). These correspond both with the isolated basins discussed above, and with troughs that cross the continental shelf in Hecate Strait and Queen Charlotte Sound. Low oxygen concentrations in troughs arise from the summer flow of oceanic waters across the shelf during months when downwelling winds have abated and weak upwelling winds blow. Note that oxygen concentrations tend to be higher in oceanic waters, compared with those at a similar depth on the shelf, because oxygen is consumed through respiration as waters cross the shelf and enter coastal inlets (Whitney *et al.* 2005a). DO levels of 2 - 3 ml l^{-1} are common in Queen Charlotte Strait, both at 100 and 200 m below surface, due to strong tidal currents that mix surface and deep waters in this region.

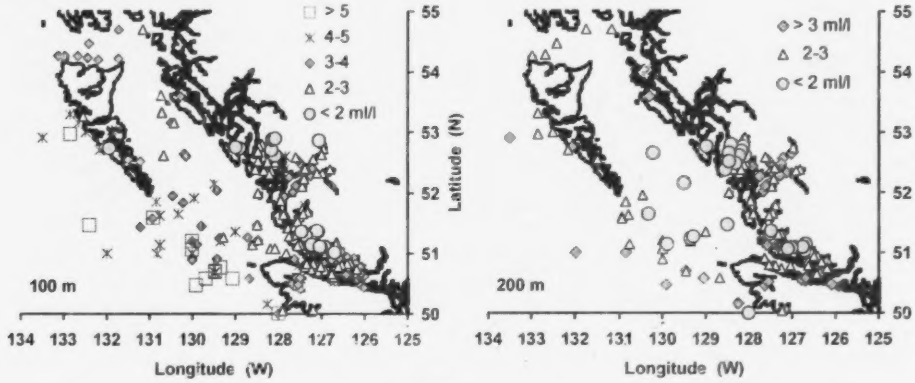


Figure C.20 Summer oxygen levels at depths of 100 and 200 m. All data between July and the end of September from the IOS archive were used to show oxygen distribution in PNCIMA.

Surveys in 1954 show the density structure and oxygen levels across Queen Charlotte Sound, across Goose Island Bank. In summer, the near-shore water to the NE of Goose Island Bank experienced lower DO levels in deep waters than observed to the SW of this bank (Figure C.21). Waters over Goose Island Bank were well mixed; consequently oxygen levels remained above 6 ml l^{-1} on both surveys. On the 26.0 isopycnal, oxygen levels were >3 ml l^{-1} on the SW side, but <3 ml l^{-1} on the NE, nearshore side, evidence of consumption by respiration in shallower, near-shore regions.

Tidal mixing freshens the near-shore waters during winter (density decreased to <25.0), and supplies oxygen to these waters. Along the SW side of Goose Island Bank the dissolved oxygen levels exhibit a summer-winter seasonal cycle in close correspondence with changes in water density brought on by downwelling.

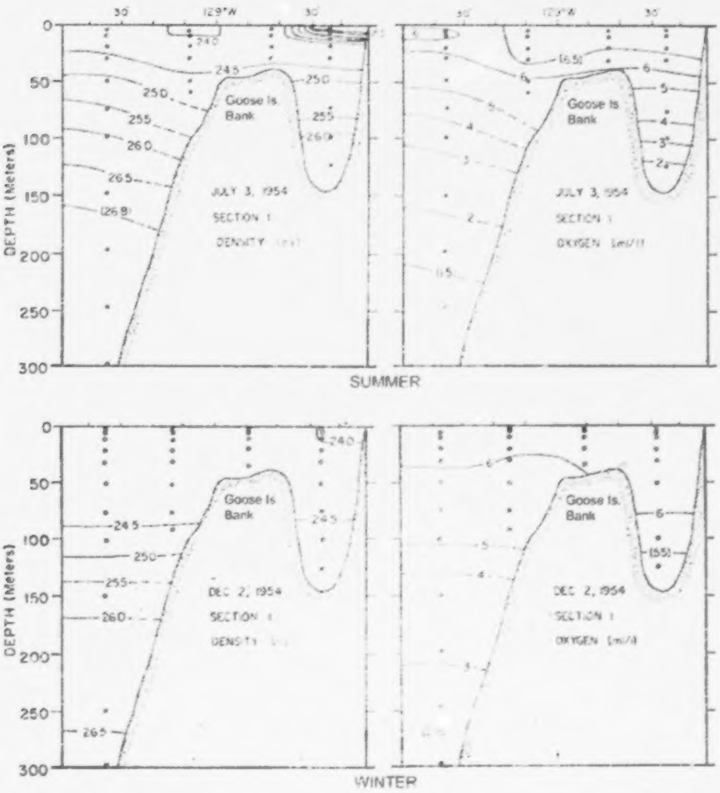


Figure C.21 Vertical sections across Queen Charlotte Sound of density (sigma-t) and dissolved oxygen (ml/l) for summer upwelling conditions (upper) and winter downwelling (lower) in 1954. The sampling line runs from southwest at left to northeast at right, ending near shore at Hunter Island (Dodimead 1980).

5.4. pH

pH is a measure of the acidity of seawater. Pure water at pH 7 is neutral, while lower pH denotes acidity and higher is described as alkaline. Seawater is generally alkaline because of its dissolved salts, having pH values typically in the range 7.4 to 8.0. Where CO_2 levels are low in the upper ocean due to plant use, pH will be near the high end of its range. ost aquatic life favours a pH of 6 to 9.

In oceanic waters, relative high pH values of 7.7 to 8.0 are generally found in the euphotic zone (upper 10 to 100 m of the ocean), decreasing to <7.5 at the oxygen minimum (800-1000 m in the NE Pacific Ocean; data from Keith Johnson, DFO). pH values are higher than pure water because of the nature of salts dissolved in seawater. Low pH values naturally occur where oxygen is low and carbon dioxide is high as a result of biological respiration. Near the sulphite mill at Port Alice on Neroutsos Inlet, low DO levels were accompanied by low pH (<7 at surface and <7.5 near bottom), compared with values away from the mill of 8.0 at the surface and 7.8-7.9 near bottom (Waldichuk 1958). Values as low as 7.0 were found in the deep waters of a Norwegian fjord where hydrogen sulphide was present (Strom 1936).

Freshwater discharge has lower pH values because of the acidity of dissolved CO_2 in water. Many streams sampled on the central BC coast during 1982-83 were slightly acidic (*e.g.*, 6-6.5 near Rivers Inlet, Sullivan *et al.* 1985). Streams with strong discoloration from humic acid exhibited the lowest pH. Coastal waters with lower salinity will have lower pH values than surface waters of the open ocean.

pH decreases (acidification) in the ocean are being observed because of rising atmospheric concentrations of CO_2 from fossil fuel use by humans. As the surface ocean becomes more acidic in future decades, some marine plankton that form calcium carbonate structures (coccolithophores, pteropods, foraminifera) may struggle to survive. The ecological impact of losing these organisms is not simple to predict.

5.5. Nutrients

Phytoplankton are the small plants that form the base of the oceanic food chain. They require mineral nutrients found in seawater for growth and reproduction. Phytoplankton also require adequate light for photosynthesis; as a result growth occurs only in the upper 10 to 100 m of the ocean. In much of the upper layer of the world's oceans nutrient levels are too low for rapid phytoplankton growth. However, on relatively shallow continental shelves, such as the PNCIMA area, nutrients are provided by several active physical processes (reviewed in Whitney *et al.* 2005a), including:

- land runoff; rivers can be nutrient-rich, particularly in silicate,
- upwelling of deep nutrient rich water,
- estuarine circulation; fresh water discharged from land creates a surface layer flow towards open ocean. Entrainment of deeper saltier water into this layer enriches it with nutrients, and also results in a deep-water counter flow that is strongest during periods of maximum river discharge. For major rivers fed by snow melt, maximum discharge occurs in spring or early summer,
- tidal mixing, often working in conjunction with estuarine circulation to bring nutrient-rich waters to the surface,
- wind mixing, either during storms or as a result of along-fjord channelling of winds between ocean and land, also mixes nutrients up to the surface,
- re-mineralization of organic materials in shallow waters and sediments.

The major nutrients required by phytoplankton include nitrate (NO_3^-), phosphate (PO_4^{-3}), dissolved silicate (silicic acid, H_4SiO_4), and ammonium (NH_4^+), as well as carbon from carbon dioxide. They also require small amounts of trace elements such as iron (Fe) and zinc (Zn). Nitrogen is used by phytoplankton to synthesize protein, whereas phosphorus is required primarily to store energy. Silicon provides a specific phytoplankton group, the diatoms, with a rigid cell structure. Reduced amounts of nitrogen, phosphorus and silicon often limit marine plant growth. Nitrate is the primary limiting nutrient in BC coastal waters. Although studies have shown that iron can limit production offshore (Martin *et al.* 1991; Boyd *et al.* 2004), a study indicated that BC coastal phytoplankton are not iron-stressed (LaRoche *et al.* 1996). Concentrations of silicate are generally high on the BC continental shelf due to large riverine sources. As a result of deep-water iron limitation and coastal nutrient enrichment, primary productivity is greater in PNCIMA than offshore, as is evident in Figure C.22. This image of phytoplankton concentrations at ocean surface was computed from observations of ocean colour by SeaWiFS sensor on the on a US satellite. SeaWiFS senses the unique colour of chlorophyll-*a* within phytoplankton, and computes the concentration of phytoplankton at ocean surface from this measurement. Figure C.22 also reveals a 100-km-diameter Haida Eddy to the west Moresby Island, containing more surface phytoplankton than found in deep-ocean waters on its west side.

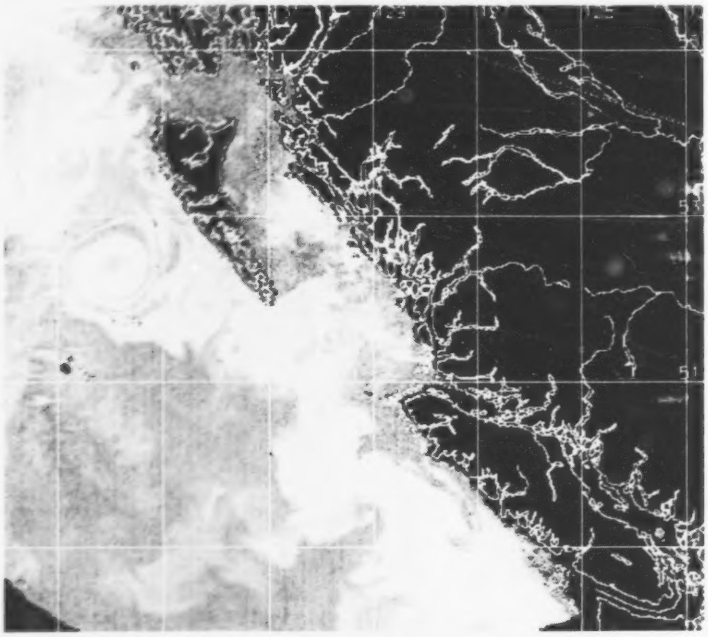


Figure C.22 SeaWiFS chlorophyll along the BC coast on 13 June 2002, showing areas of high phytoplankton concentrations (red) in regions with high nutrient supply. Concentrations decrease as the colours progress through the rainbow, with lowest concentrations denoted by blue. Black denotes clouds or no data. The swirl of high chlorophyll west of Queen Charlotte Island denotes a Haida Eddy that contains coastal waters from Hecate Strait (IOS archive). Low chlorophyll (blue) is common away from the coast, the result of nitrate being depleted from these waters.

Tidal mixing is most effective over shallow areas such as the banks, in restricted passageways such as Johnstone Strait, and around points of land such as Cape St. James and Rose Spit. If tidal mixing brings deep nutrient-rich waters upwards into a low salinity layer fed by rivers, the mixed waters are more likely to remain on the surface and support rapid growth of phytoplankton. This process may be active in regions such as Brown Passage, Edye Passage, and Hakai Passage and perhaps through the Sea Otter Group of islands and nearby reefs.

Winter storms mix shelf waters, bringing nutrients up from depth. In spring, solar energy increases to a level where coastal waters thermally stratify, and phytoplankton can rapidly grow. The timing of spring growth, denoted the spring bloom, depends on warming of the ocean and is typically earlier in warm years. Plankton productivity remains high during spring and summer, depending on nutrient availability.

In Figure C.23, areas of high nitrate at surface in summer correspond to regions with strong mixing. Especially obvious is the high-nutrient outflow from the tidally mixed passages of Johnstone and Queen Charlotte straits. These nutrient-rich waters flow seaward across the north end of Vancouver Island. Nutrients are moderately abundant also in coastal passes leading towards Skeena River in the northern part of the figure. In Hecate Strait, nutrients are still available to phytoplankton, but diminish as surface waters flow from coastal inlets towards the open ocean (Whitney *et al.* 2005a). Waters in outer Queen Charlotte Sound and off the continental shelf remain nitrate-depleted for most of the summer following the spring bloom.

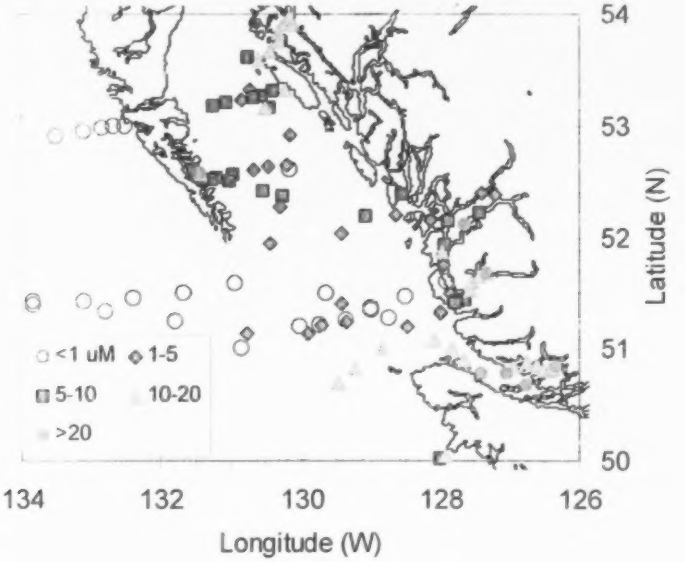


Figure C.23 Nitrate concentrations (umol l^{-1}) in surface waters of PNCIMA in summer. Data from 2003, 2004 and 2005 surveys in August or September were combined to show areas of high and low nitrate.

Rare Hexactinellid sponge reefs, recently discovered in Queen Charlotte Sound and Hecate Strait (Conway *et al.* 1991), are located in water depths of 165 to 230 meters near the head of the deep troughs that cross the continental shelf (Appendix A: Geology Figure A.16). The sponges occur in areas where the bottom is composed of ice-furrowed glacial till (DFO 2000). Conditions here are favourable to these glass sponges because of the proximity of deep, silicate-rich waters that flow into the troughs from offshore. Additional silicate in these waters is derived from re-mineralization of silica near or within shelf sediments.

5.6. Turbidity

Turbidity is a measure of the cloudiness or opacity of water caused by suspended particles and dissolved material. It was traditionally measured with a Secchi disk, a white disk that is lowered into the water to measure the light attenuation by particles in seawater. In recent years, light attenuation has been measured by a tranmissometer attached to profiling electronic sensors deployed from ships. As noted in Appendix A: Geology, the continental shelf in PNICMA has low sediment deposition because most of the fjords and inlets of the coast allow river-borne sediments to settle out within their basins.

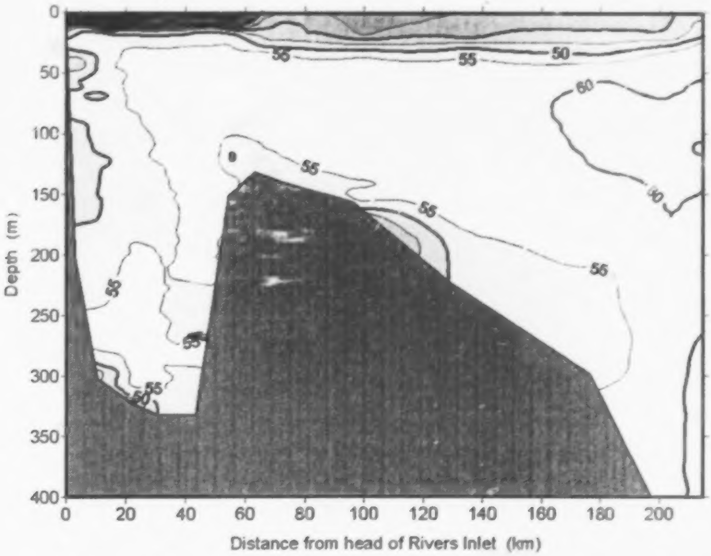


Figure C.24 A September 2003 survey section from the mouth of Rivers Inlet (left) to the outer edge of Queen Charlotte Sound (right), showing particle distribution as % light transmission in seawater. Values above 60% indicate very low particle densities. Notice the high particle load in surface waters of Rivers Inlet and evidence of deposition at depth (Whitney 2002).

Fine particles may still reach the area just beyond the mouths of coastal inlets. The range of Secchi disk depths in BC coastal waters is from 4 to 20 m (Parsons 1965). The greatest light penetration is found in the deeper and more open waters and generally in the winter; the lower values would be found near the mouths of inlets especially in the summer during high runoff and peak plankton productivity (Figure C.24). Estuaries and inlets are clearly more turbid. For example, Waldichuk *et al.* (1968) recorded Secchi disk depths of 0.9 m at the mouth of the Skeena River, but 7 m in Chatham Sound. In the open waters of Dixon Entrance the Secchi disk depths were found to range from 10 to 20 m. Again lower values are associated with higher runoff in summer (Petro-Canada 1983).

Turbidity can also be increased by re-suspension of bottom sediments. For this turbidity to affect surface waters requires strong wave/wind mixing and/or strong tidal currents as well as a shallow source of sediments. The Dogfish Banks are mostly less than 20 m deep and floored by fine to medium grained sediments, so this area on the northwest side of Hecate Strait is often quite turbid. Cook and Goose Island banks may also show increased surface turbidity under the right conditions. Many areas of the shelf experience high turbidity near the sea floor due to tidal currents that keep fine particles in suspension. This generally is restricted to within a few tens of meters of the sea floor and has been observed in the troughs in Queen Charlotte Sound. Higher particle density in troughs may be important in the growth of hexactinellid sponges as they appear to filter much of this turbidity out of the water column in their immediate vicinity (Whitney *et al.* 2005b).

5.7. Natural Hydrocarbons

Natural oil seeps have been found on the Queen Charlotte Islands. Thus, a potential source of natural hydrocarbons in PNCIMA waters would be submarine seeps of both oil and natural gas. The BC coast has been assessed as an area of "moderate seepage potential" (Wilson *et al.* 1974). The PNCIMA marine region is underlain by the highly prospective Queen Charlotte Basin which is thought to contain significant amounts of oil and gas (Appendix A: Geology). Studies of natural hydrocarbons in BC's coastal waters are few and dated (Chevron Canada Resources Ltd. 1982; Petro-Canada 1983). Researchers at DFO's Institute of Ocean Sciences have begun studies in the Queen Charlotte Sound and Hecate Strait area to determine background levels of hydrocarbons, define their chemical signature, and to begin the search for hotspots (F. McLaughlin, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2005). Added to these natural sources of hydrocarbons would be oil pollution as a result of spills and chronic oil spills/leaks from shipping traffic. This is discussed further in Haggarty *et al.* (2003) and the PNCIMA Marine Use Analysis (Fisheries and Oceans Canada 2007) and the oil and gas studies of the area (Chevron Canada Resources Ltd. 1982; Petro-Canada 1983). Seasonal shipping traffic patterns are shown in Figure C.31.

5.8. Spatial and Seasonal Variability

The shelf waters of the BC central coast (Queen Charlotte Sound and Hecate Strait) are considered coastal waters, based on the nutrient supply and utilization (Whitney *et al.* 1998). Between the coastal waters and the oceanic waters lies a 'southern transition/California Current' zone that has very little silica and low nitrate.

Nutrient levels in the coastal waters on the BC central shelf region decrease quickly during spring uptake by phytoplankton. Subsequent growth depends on processes that transport nutrients up into the surface layer. In areas of tidal mixing, nutrients are continuously provided to the upper ocean, making regions downstream from active mixing sites very productive (Figure C.22). Shallow shelf regions are more strongly mixed during summer wind events, keeping regions like Dogfish Banks off the northeastern edge of Queen Charlotte Islands very productive also.

Every winter, Haida Eddies transport large amounts of continental shelf water offshore, carrying with them heat, fresher water and organisms from this region (Crawford 2002; Crawford *et al.* 2003; Mackas and Galbraith 2002; Whitney and Robert 2002). These eddies have nutrient characteristics similar to Hecate Strait winter water (Whitney and Robert 2002). The largest eddies occur during strong El-Niño years, such as 1997/98. These eddies also contain high levels of iron and other trace elements which are normally depleted in the Alaskan gyre. This transport stimulates phytoplankton growth in offshore waters, as shown in Figure C.22.

5.9. Interannual and Long-Term Variability

Major ocean-climate events, such as the ENSO cycle, cause variability in nutrient levels along the BC coast and affect productivity. For example, upwelling tends to be suppressed during El Niño events, which inhibit the transport of deep-water nutrients onto the continental shelf. During the 1997/98 El Niño, strong surface-water nutrient depletion occurred in the spring and summer (Whitney and Welch 2002). Conversely, during La Niña events, surface nutrient concentrations are higher, and the maximum chlorophyll levels are found closer to shore (Whitney and Welch 2002).

There has also been a long-term warming of surface waters in the eastern Gulf of Alaska (Freeland *et al.* 1997), that has increased upper ocean stratification, decreased oxygen levels in the interior ocean and reduced nutrient concentrations in the mixed layer. Shore stations along the BC coast report an increase in temperature over the past 50 years, with a warm period in the 1990s and again in 2004-05. (A summary of these temperature changes is presented at the Web site: http://www.env.gov.bc.ca/soe/bcce/). Reduced nutrient levels have lead to reductions in primary production (Whitney *et al.* 1998). Changes in ocean stratification and nutrient supply have serious consequences for higher trophic levels (see Appendix D: Plankton and Appendix K: Marine Birds).

Long-term trends in oxygen along the BC coast can be inferred from measurements made over the past 25 years. In the open ocean at a station with a 50-year record of oxygen measurements (Ocean Station Papa; 50 N, 145 W), a persistent declining trend can be seen on density surfaces found between 150 and 400 m depth (Whitney 2002). These trends show oxygen declines of 0.72 and 0.63 μmol kg^{-1} y^{-1} on the 26.5 and 27.5 isopycnal surfaces. Tracking changes on density surfaces eliminates variability caused by changes in buoyancy of the upper ocean. Since oxygen is transported into the interior of the ocean along density surfaces, it also shows episodes when the ocean oxygen supply is replenished.

On the west coast of Queen Charlotte Islands, similar patterns of oxygen change are observed (Figure C.25). Linear trends show a slower rate of oxygen decline on the 26.5 isopycnal surface (-0.50 μmol kg^{-1} y^{-1}) than that seen in open ocean, but a more rapid decline is seen on the 26.7 surface (-1.09 μmol kg^{-1} y^{-1}). On the deeper surface, the rate of oxygen decline is ~1% per year. It is difficult to look for trends on the shelf because of the high interannual variability seen in these waters and data scarcity.

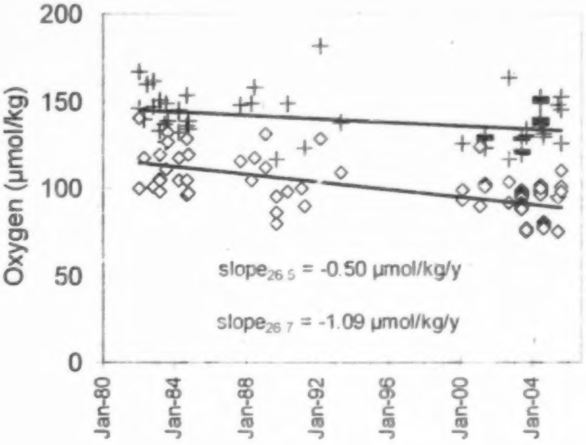


Figure C.25 Oxygen trends on the 26.5 (+) and 26.7 (◇) isopycnal surfaces, west of the Queen Charlotte Islands (to 134°W) between 51°N and 53°N. Data are from the IOS archive. The 26.5 and 26.7 density surfaces correspond to depth ranges of 150 to 225 and 200 to 275 m respectively).

In the NE Pacific, a surface warming trend is observed in most data sets (Freeland *et al.* 1997). A warmer surface ocean results in stronger stratification of the ocean, with the result that it is more difficult to mix the surface ocean. Less mixing will result in less oxygen being provided to the interior of the ocean. This is a well understood consequence of global warming (*e.g.*, Woods and Barkmann 1993), and could lead to loss of habitat for marine organisms that cannot tolerate low oxygen. Organisms unaffected by hypoxia could expand their habitat.

6.0 COASTAL INLETS AND FJORDS

The BC coastal zone is a maze of waterways, inlets and fjords that are important ecologically, economically and sociologically. They support fisheries, aquaculture, tourism, recreation, shipping, logging, and various other uses. Developmental pressures are increasing, highlighting the need to better understand the oceanography for proper coastal zone and marine use management.

The coastal zone is exposed to the general offshore climatic patterns, but also has specific characteristics due to the land's topography and the proximity of the Coast Mountains. The steep mountains can cause increased precipitation at the heads of the inlets. Cold winds can flow down off the ice fields at night, while daytime summer heating can generate stiff diurnal breezes. In winter, gaps in the mountains can allow cold 'polar' outbursts of continental air to reach coastal areas (Tyner 1951; Lange 2003).

6.1. Existing Studies

The Institute of Oceanography at the University of British Columbia (later the Department of Oceanography) has been conducting coastal BC cruises since 1951 and much of our knowledge of BC's inlets and fjords is based on their studies (Pickard 1961; 1963; Pickard and Stanton 1979). An early study by government fisheries personnel looked at converting Seymour-Belize Inlet into a freshwater sockeye producing basin (anon 1962). Pollution-related studies have been conducted largely by the Canadian Department of the Environment, and a recent overview has been published by DFO (Haggarty *et al.* 2003). Some specific sites, such as the pulp mill at Ocean Falls, were monitored closely (Packman 1979). The Province of British Columbia has funded summaries of the central and northern coast (Ricker and McDonald 1992; 1995; Ricker *et al.* 1989; Ricker and Seakem Group 1989a; 1989b; Ricker 1989), on topics related to aquaculture, and these reports capture much of what is known historically.

Few inlets have been studied in any detail, the exceptions being Knight Inlet, the Bella Coola estuary (Fitz Hugh Sound/Burke Channel), Rivers Inlet (Whitney 2002), the Kitimat system (Webster 1979) and Rupert-Neroutsos Inlets. Knight Inlet, particularly the sill dynamics, has and continues to be, studied extensively. The Bella Coola (or Burke Channel) estuary was studied from 1963 to 1967 to investigate the large runs of pink salmon (Herlinveaux 1973). Subsequently, a program began in 1974 to evaluate major BC estuaries that were deemed critical estuaries in terms of their natural living resources and their vulnerability to impact by human activities. The series covered 10 estuaries including the Skeena (Hoos 1975), Kitimat (Bell and Kallman 1976), Bella Coola (Leaney and Morris 1981), and Campbell River (Bell and Thompson 1977) estuaries. Although dated, these studies are very detailed and cover most of the topics included in this report. Aquaculture proposals for the Bella Bella area resulted in two (unpublished) feasibility studies (Entech Environmental Consultants 1981; 1985). Many of the data that have been collected for these studies were from spring/summer only.

Both Rupert Inlet and Neroutsos Inlet on northern Vancouver Island have been examined over the past 40 years to determine impacts of mining and a pulp mill, respectively.

Ongoing studies by Dario Stucchi and Michael Foreman of DFO's Institute of Ocean Sciences are focussed on waters of the Broughton Archipelago, as are a host of sea lice research programs.

6.2. Runoff and Estuarine Circulation

BC's glacial-carved fjords tend to be deep (down to 764 m in Jervis Inlet) with steep sides, flat bottoms, and sills or shallow ledges where they meet the ocean. The Burke Channel, Dean Channel and Fitz Hugh Sound waterway extends 150 km inland from Queen Charlotte Sound, and exchanges deep waters across two constricted sills of ~125 m depth. Freshwater input is a critical factor controlling fjord circulation and water properties, as the input of fresh water drives the estuarine circulation (Pickard and Stanton 1979). Along the mainland, most fjords have a maximum in freshwater input in the late spring through summer due to snowmelt.

Mainland fjords are often classified according to the amount of freshwater runoff they receive from snowmelt (BC MSRM 1998; Pickard 1961):

- **High Runoff**: These fjords penetrate far enough inland to tap into glacial watersheds that provide runoff throughout the summer, not just during spring melt. They characteristically have dilute, silt-laden surface layers 3-10 m thick that persist through the summer. Estuarine flows at surface are about 10 cm s^{-1}. Examples include Burke and Dean channels, Knight and nearby Kingcome inlets.
- **Intermediate Runoff**: These have less glacial runoff, but sufficient snow pack to produce substantial spring runoff. The surface layer is not as thick, only about 2 m. Examples include Seymour, Belize and Neroutsos inlets.
- **Low Runoff**: Runoff occurs only during spring melt and produces only a partial dilution of the surface layer, and weak estuarine flow. The pycnocline begins close to the surface. Rupert-Holberg Inlets are an example.

Many of the inlets and fjords along BC's coast have been classified according to this system, but not all (Pickard 1961; Pickard and Stanton 1979; Ricker *et al.* 1989; Ricker and Seakem Group 1989a; Ricker 1989; Ricker and McDonald 1995).

Some inlets receive very little snowmelt and do not fit the above classification (*e.g.*, Vancouver Island and Queen Charlotte Islands inlets). They tend to have peak freshwater inputs in the fall and winter when the local precipitation is at a maximum. Other classifications also exist that differentiate as to whether a sill is present, the importance of tidal mixing, and the degree of stratification.

Freshwater discharge is discussed in section 2.0. Discharge has also been estimated for some individual inlets and sounds along the BC coast, but these estimates are quite dated (Trites 1955).

The estuarine circulation helps flush the deeper waters, although sills at the entrance often limit this effect. Poor flushing can result in reduced levels of dissolved oxygen, low biological productivity and low species diversity. However, such fjords can also be home to important and often unique species of benthic and planktonic communities (BC MSRM 2002). Figure C.26 illustrates some of the processes that occur in BC's coastal inlets/fjords.

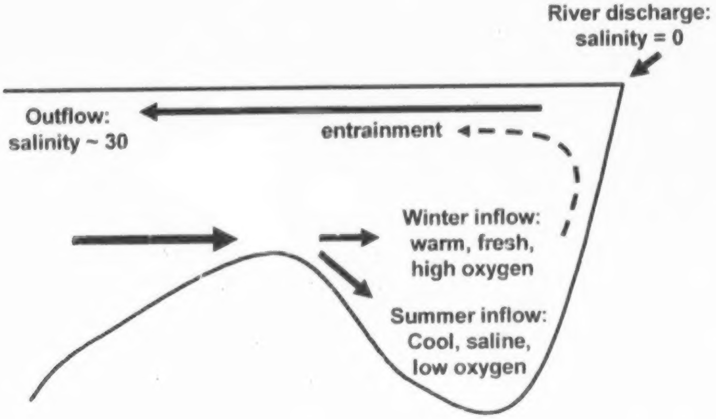


Figure C.26 Schematic of estuarine circulation in an inlet with a sill near its entrance, showing surface outflow throughout the year, deeper winter inflow of relatively warm fresh waters into coastal inlets, and summer inflow of dense waters. Fresh water from rivers at the head of mainland inlets drives estuarine circulation, resulting in the entrainment of saline, nutrient replete waters from below.

Estuarine flow is strongest during periods of high runoff, but can be also be modulated by tides, winds and oceanographic conditions offshore. The outflow of the fresher surface waters in the Burke Channel estuary is held up by periods of southerly winds, then enhanced when the winds switch to northerly (Dodimead and Herlinveaux 1968; Herlinveaux 1973). Estuarine-driven surface currents in Burke Channel reach speeds of 100-200 cm s^{-1}, with a significant reverse flow below the halocline.

6.3. Deep-water Renewal

Deep-water renewal of waters in BC inlets typically occurs in summer, during the period when densest bottom waters are found on the continental shelf. Deep-water flushing is episodic, particularly when there is a restrictive sill at the entrance or multiple sills as in Spiller and Roscoe inlets (Ricker and McDonald 1995). Dense water capable of penetrating the deeper portions of the inlet will appear in summer when downwelling winds abate. Even then, the density of the water penetrating over the sill is often reduced by tidal mixing with surface waters.

Seasonal profiles of temperature, salinity, dissolved oxygen, and nutrients, obtained in Rivers Inlet have been used to understand the seasonal trends and patterns of deep-water renewal (Whitney 2002). Waters transported into the inlet during winter are relatively warm, low in salinity and nutrients, but high in DO (Figure C.27). There can be significant gradients in water properties along the inlet, especially in winter and spring when water exchanges between the inlet and Queen Charlotte Sound may be occurring. By late August in 2003, inlet renewal had occurred according to current records of that summer (Whitney 2002).

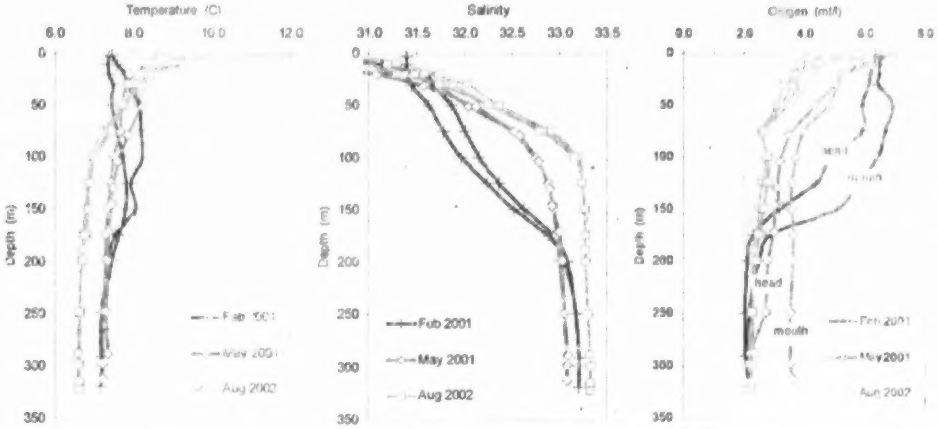


Figure C.27 Water profiles collected in Rivers Inlet in winter, spring and summer during 2001 and 2002. Densest (cool, high salinity) waters were found in August 2002, following deep-water renewal. These profiles were chosen as representative of winter, spring and summer from more than a dozen surveys that visited the inlet between 1998 and 2004 (Whitney 2002).

In summer, bottom waters approaching the sill are cooler, more saline, nutrient rich and oxygen poor. These dense waters flow into the inlet during periods when winds are upwelling-favourable. The impact of upwelling winds is not well defined in PNCIMA, but weakly upwelling-favourable winds do allow the most dense sub-surface waters of the year to cross the Queen Charlotte Sound shelf and flow into Rivers Inlet (Whitney 2002). The deep waters that enter Rivers Inlet in summer through a 125 m deep trench south of Calvert Island, and possibly through Hakai Pass, are also found in basins throughout the Fitz Hugh Sound, Burke Channel and Dean Channel area. Peak currents measured in bottom waters near the entrance to Rivers Inlet in the summer of 2003 exceeded 45 cm s^{-1} during three inflow events recorded between June 22 and August 9 (Whitney 2002). Inflow occurred on rising tides, persisted for several hours on each tidal cycle, and continued for 7 to 10 days while winds were upwelling-favourable.

An important result of these basin renewals is that nutrient levels increase substantially in the intermediate waters. This enrichment results in more nutrient being entrained in surface outflow waters, undoubtedly boosting the primary productivity of the region. Winter intrusions of shelf waters into the Kitimat fjord system at intermediate depths probably occur during periods of katabatic winds when the surface waters in the inlet system are driven seaward (MacDonald *et al.* 1982).

6.4. Water Properties

The temperature of the surface waters in the coastal inlets can reach the low 20s °C during summer. Conversely, near-zero temperatures can occur during winter, particularly in the upper reaches of inlets that have frozen, runoff-diluted surface layers. Salinities can range from oceanic values in recently added deep waters to near zero at the surface in high runoff inlets.

Surface dissolved oxygen (DO) levels in the inlets are generally high and can supersaturate during spring plankton blooms. Oxygen levels tend to decrease with depth. In BC fjords, exchange between deep and surfaces water is usually enough to keep oxygen levels above 2 ml l^{-1} in large basins (Pickard 1961; Pickard and Stanton 1979). Historical deep-water oxygen levels in Knight Inlet (2.5-5.5 ml l^{-1}) have generally been higher than those of the more southerly inlets. Deep-water DO levels can also be low if there is significant decay of organic material that increases the biological oxygen demand. Examples are debris from logging in Call and Seymour inlets, and pulp mill waste accumulation at Port Alice and Cousins Inlet, although DO levels in Cousins Inlet may recover as a result of the mill closure in 1980. Anoxic waters at bottom can be expected in inlets with little freshwater flow and restrictive sills, such as Spiller, Roscoe, Smith and parts of Belize and Seymour, as noted previously.

Turbidity levels within the fjords are generally higher in summer due to the suspended particles in the freshwater input, sometimes called ‘rock flour’ (Figure C.24). Most of the particulates are resistant to dissolving and do little to alter the water chemistry. The run-off in some areas has a limestone ‘flavour’, raising the pH of the receiving waters (Ricker and McDonald 1995). For high runoff fjords a Secchi Disk, used to quantify water clarity, may be visible only within the first 10 - 30 cm (Pickard 1961). Plankton and brownish humic acid runoff also decrease water clarity.

For photosynthetic plankton, turbidity reduces the depth of the euphotic zone, and requires mixing of nutrients higher up above the halocline. Whether natural (“rock flour”), or man-made (*e.g.*, logging debris), turbid waters result in reduced primary productivity. Turbidity levels tend to decrease toward the mouth of the inlet as particles flocculate and sink from the surface layer. As near-surface turbidity levels reduce toward the mouth of an inlet, primary productivity increases.

Often, turbidity levels increase towards the bottom again in the deepest 50 to 100 m of the water column. High near-bottom turbidity can be due to resuspension by bottom currents, turbidity currents and landslides/avalanches. Turbidity plumes have been observed in Moses and Rivers inlets. Avalanches and landslides, as in Dean Channel, often scar the steep sides of the inlets. Highly turbid waters can be detrimental to filter feeders, causing them to silt-up, and turbidity currents would be harmful to any benthic creatures in their path.

6.5. Long Term Trends in Water Properties

Oceanographic studies of BC's inlets and fjords, dating back to 1951 by the Institute of Oceanography at UBC provide a long (~50 year) time series. Recent analyses of these data show an increase in bottom water temperatures of about 0.5 to 1°C in most BC inlets since the mid 1970s (Stucchi 2003). No trend was observed in the deep-water salinity or dissolved oxygen.

In Figure C.28, a warming trend is obvious in inlets within PNCIMA. Data are scarce, compared to the better studied inlets to the south, but trends are the same; basin waters have warmed by 0.5 to 1°C since the early 1950s. The relatively highest temperatures in deep waters of central coast inlets were observed during the 1997-98 El Niño, with cooler waters being observed since. Climate events such as these add considerable variability to time-series trends.

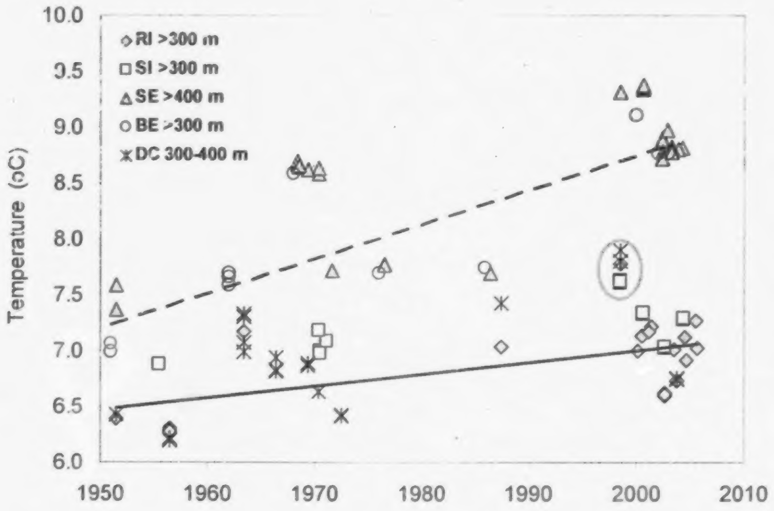


Figure C.28 Trends in basin water temperature for inlets on the central coast of BC (RI – Rivers Inlet; SI – Smith Inlet; SE – Seymour Inlet; BE – Belize Inlet; DC – Dean Channel). Linear regressions for Belize (dashed line, 0.31 °C decade^{-1}) and Rivers Inlets (0.11 °C decade^{-1}) show the range of warming observed (Whitney 2002). The red circle highlights warm temperatures during the 1997-98 El Niño.

The rate of warming in this set of inlets is related to the salinity of basin waters, the lower salinity basins warming more rapidly. Seymour and Belize, with basin salinities of 29 to 30 are seeing warming trends of 2 to 3°C century^{-1}, whereas Smith, Dean and Rivers have bottom salinities near 33 and warming trends of 0.7 to 1.7°C century^{-1}. Basin salinity is governed by the depth of an inlet's sill and the mixing that occurs as waters flow in. Both a shallow sill and more mixing will permit atmospheric warming to be recorded in basin waters more effectively. Inlets with deeper sills are insulated from direct local atmospheric warming.

With increasing development of the BC north and central coast, increasing temperatures, and stronger ocean stratification, one might expect DO levels in the deep waters of the inlets and fjords to decline. This trend is not observable due to strong seasonal trends in basin oxygen and scarce time-series data.

7.0 LONG-TERM VARIABILITY

Changes in climate-ocean conditions with time scales exceeding seasonal are known to affect BC coastal waters. The most significant interannual signal is forced by El Niño Southern Oscillation (ENSO). Decadal or multidecadal oscillations have been described, using various climate indices. However, the most persistent trend seen in temperature records of the past century appear to be associated with global warming.

7.1. El Niño Southern Oscillation (ENSO)

ENSO is a cyclical large-scale atmosphere-ocean event with alternating cycles of El Niño and its counterpart La Niña. Strong El Niño events were traditionally associated with warmer waters off Ecuador and Peru and a collapse of the fishery there; however, it is now recognized as a cyclical event having near-global consequences to ocean and atmospheric conditions. ENSO events occur every few years, with strong El Niños occurring about every ten years (Quinn 1992) as shown by the large red peaks in Figure C.29 in 1957/8, 1972/3, 1982/3, 1991/2 and 1997/8. The last strong El Niño event occurred in 1997-98.

In the early stages of El Niño, the trade winds along the equatorial Pacific relax, allowing a large mass of warm surface ocean water to surge back onto the South American coast. During strong El Niño events the equatorial waters continue flow northward up the west coast of North America reaching into Canadian waters during extreme El Niño years. The Aleutian Low Pressure system often strengthens during El Niño winters, and severe winter storms often track farther south through the USA rather than into BC. Both these changes in weather bring warmer waters to British Columbia, and their combined impact exceeds that of the more passive flow of warm water northwards from the Equator. Effects on BC coastal waters during strong El Niño events include:

- Milder air temperatures (~1-2°C) and warmer coastal waters (~1-2°C). From Dec. 1982 to Feb.1983 air temperatures were 2.1°C warmer than normal http://www.smc-msc.ec.gc.ca/education/elnino/canadian/region/index_e.cfm?region=pacific_coast. Waters offshore BC were warmer by 1-2°C (Crawford 2001) than during the La Niña of 1988 - 1989. The milder weather conditions can cause earlier spring snowmelt, changing the timing of freshwater input to coastal rivers and inlets.

- Rises in sea level above normal seasonal heights. During the winters of 1982-83 and 1997-98 water levels at Bella Bella were up to 35 cm above the seasonal norm (Figure C.15) (Crawford *et al.* 2002a).
- Coastal downwelling is more common during El Niño, and this holds fresher water near the coast and affects the deep-water renewal of the inlets (Crawford *et al.* 2002a; F. Whitney, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2003).
- Spring blooms are earlier and possibly weaker (Whitney and Welch 2002), affecting the timing of zooplankton development (Mackas *et al.* 1998) and reducing the reproductive success of seabirds (Bertram *et al.* 2001).
- Shifting of salmon migration routes in response to the arrival of warm waters from the south (Mysak 1986). Mackerel, a warm water species, preys heavily on the juvenile salmon. The production of Fraser River sockeye salmon may also relate to decadal-scale changes in the climate and the ocean (Beamish *et al.* 1997). Possibly related are inter-decadal variations in coastal fresh water with implications for biological productivity (Royer *et al.* 2001).

Conditions following an El Niño event generally return to normal; however, occasionally the equatorial trade winds become overly strong, initiating a strong La Niña (large blue troughs on Figure C.29). Strong La Niña events have been blamed for unusually cold winters in western Canada, and wet winters in southwestern Canada.

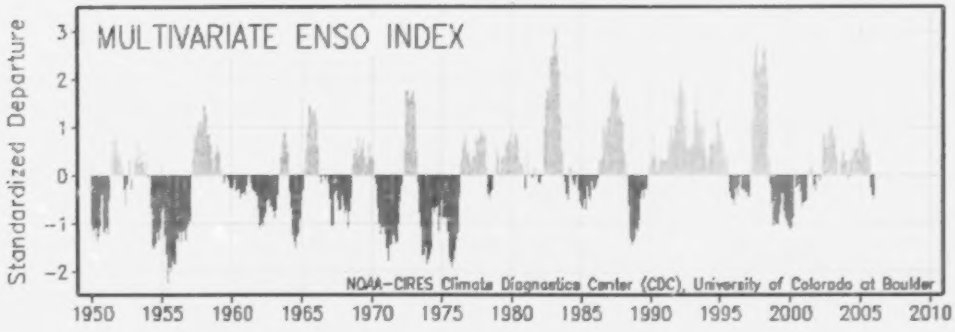


Figure C.29 Plot of a multivariate ENSO index, based on: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature and total cloudiness fraction of the sky. Red= El Niño; blue= La Niña (www.cdc.noaa.gov/~kew/MEI/).

7.2. Multidecadal oscillations

The severity of El Niño effects off BC are believed to be modulated by the Pacific Decadal Oscillation (PDO) (Mantua *et al.* 1997; Furtado 2002) whose warm/cool phases have a periodicity of a few decades. The strong 1997/98 El Niño occurred at the end of a warm phase of the PDO in the Gulf of Alaska (Figure C.30), compounding its severity. Conversely, the PDO phase associated with cooling of the northeastern Pacific can suppress El Niño effects in the Gulf of Alaska.

The idea that there is a several decade-long variation between wet-cool and warm-dry periods in the NE Pacific is supported by tree ring records showing periods of strong and weak growth (Ingraham *et al.* 1998). It is entirely uncertain, however, how such historical patterns of variability will be influenced by an accelerating global warming trend.

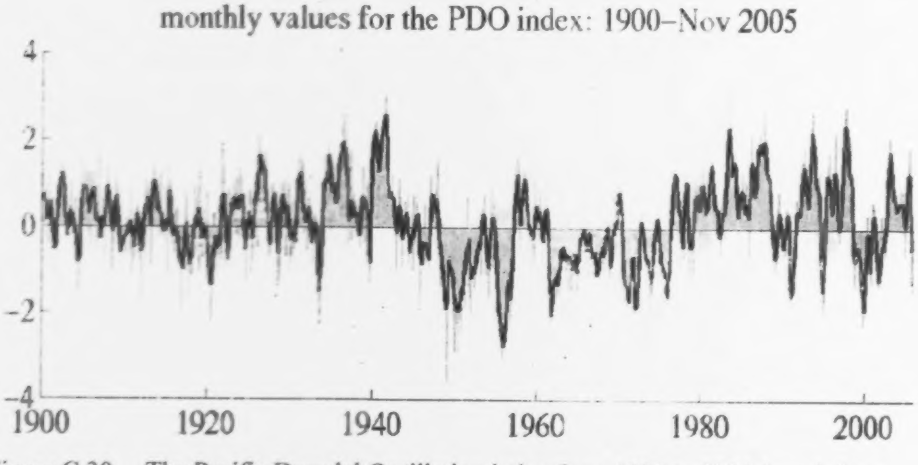


Figure C.30 The Pacific Decadal Oscillation index from 1900 to 2004 (graph from http://tao.atmos.washington.edu/pdo/graphics.html).

McKinnell and Crawford (2007) have noted significant modulations in daily-minimum winter air temperatures and in shore-station sea temperatures due to the 18.6-year lunar nodal cycle. Coldest temperatures are in years of maximum lunar declination (moon highest in the sky) such as 1987 and 2006.

7.3. Global warming

The global atmosphere has been warming during the last 100 years, with the rate increasing over the past 30 years. It has resulted in ocean-atmosphere changes to the central BC coast, including:

- ***Rising sea level***: Sea level at Prince Rupert has been rising at a rate of 11-12 cm per century over the past 95 years (BC MWLAP 2002; DFO 2002). This is due to a combination of global sea level rise (~10-20 cm century^{-1}) and vertical movement of the coast (Thomson and Crawford 1997). The central BC coastline is relatively steep, minimizing the risk of flooding, however many population centres are close to sea level, and there may be other, as yet unidentified, consequences. Sea levels are expected to continue to rise during the next century, possibly at an accelerated rate. The northeast coast of Graham Island is especially vulnerable to sea level rise and erosion.
- ***Warmer surface waters***: Sea surface temperatures in Queen Charlotte Sound are increasing at a rate of about 1.6°C per century according to analysis of lighthouse data from 1937 to 2001 (Freeland *et al.* 2001). Salinities in the northeast Pacific over the last 60 years have declined (Freeland *et al.* 1997). Temperatures are expected to continue to warm, subject to inter-decadal variability. Warming of the ocean threatens cool water fish species, particularly sockeye salmon (BC MWLAP 2002). Other species are also at risk, such as the auklets that nest on Triangle Island. Studies have shown that survival of the chicks is very sensitive to water temperature, with high failure rates when temperatures exceed 10°C (see Appendix K: Marine Birds).
- ***Warmer deep waters in inlets***: Trends suggest warming is occurring at rates from 0.7°C to 3°C per century. Increasing water temperatures will have an effect on metabolic rates of many organisms, perhaps increasing remineralization rates of detrital organic materials, thus placing a higher demand on oxygen. Development rates of zooplankton could change, resulting in a timing mismatch between them and various prey species.
- ***Changes in hydrological cycle***: The warming has resulted in an increase in precipitation on the central and north coast. This may cause more landslides in the steeper inlets and fjords. Summer river discharges are up partly due to increased precipitation, but also due to an increased rate of glacial melt. Eventually this could result in the complete loss of some glaciers which would reduce summer flows and shift the hydrodynamics of mainland inlets/fjords to a winter peak in flows. Further to the south, the Fraser River is becoming warmer, and the period of peak discharge is occurring sooner each year. All these changes to freshwater discharge affect timing and degree of estuarine circulation, timing of the plankton bloom and other ecosystem functions.

8.0 SOUND ENVIRONMENT

8.1. Sound Intensity and Frequency

Sound travels as a pressure wave that propagates through any compressible media. As a wave, its commonly measured properties are the frequency, or wavelength, and pressure amplitude, as well as its average intensity.

The sound wave average intensity refers to the power carried by the wave through a unit area and can be expressed as sound intensity level or as sound pressure level using the logarithmic scale. The unitless logarithmic decibel (dB) scale is used to express sound level and is problematic because it is derived relative to a reference level much like earthquake magnitudes. This means that a sound that is increased by 20 dB has a pressure amplitude 100 times greater; an increase of 30 dB means pressure amplitudes 1000 times greater, etc. Decibels can be calculated either from sound intensity (watts per square meter) or from sound wave pressure (Pascals, Pa). This is done in three ways in the literature and can cause some confusion if the method is not taken into account, as each method produces slightly different results. Sound levels can be expressed in terms of root mean square (RMS), peak-to-peak (p-p), or zero to peak (0-p) units (Gausland 2000).

The common reference levels in air and water are different so, for example, 140 dB in air, which is above the threshold of pain, using a pressure reference of 20 μPa is equivalent to 166 dB in water using a pressure reference of 1 μPa. This is approximately the commonly used limit for acceptable sound pressure levels in the marine environment. Every time the dB scale is used it should be identified whether the values are RMS, p-p, or 0-p, and the reference pressure should be clearly stated. While the intensity (dB) speaks to how loud a sound is, the frequency in Hertz (Hz = cycles per second) is important to audibility. Humans can detect sounds from 1 to 140 dB p-p re 20 μPa in the frequency range from 20 to 20,000 Hz. This is significant because if the sound is outside a given organism's frequency range, the intensity is not relevant. An example is the dog whistle, which can be irritating to dogs but is totally inaudible to humans even at high intensity. Thus it is important in discussion of the effects of sound, to state both the frequency and the intensity.

8.2. Sound Propagation

In seawater, sound propagation is strongly dependent upon the temperature, pressure, and salinity of the water it is moving through. Thus, sound travels at different speeds in different parts of the ocean. Most places in the ocean (PNCIMA included) are prone to vertical layering and can be divided into at least a surface mixed layer and a deep-water layer, although further divisions can usually be made. The interface of these water bodies produce refraction surfaces, much the way light is refracted moving from air into water. Since sound bends towards a region of slower sound speed, sound energy is focused around velocity minima. This phenomenon is known as the sound channel or the SOund Fixing And Ranging (SOFAR) channel. In short, sound energy can become trapped and focused within layers in the ocean and is then propagated much further within these layers than would otherwise be expected. Conversely, refraction of sound can produce shadow zones in which sound is poorly propagated. This commonly occurs in the mixed surface layer (Urick 1983). Predicting the propagation of sound in the ocean thus requires a fairly extensive knowledge of basic water properties at a variety of depths.

Sound-wave dissipation increases with frequency. High frequencies, such as in the 20 KHz range and above, dissipate more rapidly with distance from the source as a result of energy loss due to the interaction with water molecules. Low sound frequencies are transported much farther as these interactions are minimized. Marine mammals that travel large distances take advantage of this by utilizing low frequencies to communicate with others in migrating groups that may be widely spread out.

Finally, in shallow waters (<200 m) sound propagation is strongly affected by the sea floor topography and substrate material and sea surface conditions (Urick 1983). This can strongly affect ambient noise levels such that they tend to be much higher than in deep water with similar noise sources if the bottom is very reflective, but much lower if the bottom material is absorptive (Richardson *et al.* 1995).

Figure C.31 (below) illustrates the density of large commercial ships through each 5 by 5 km square in PNCIMA in winter and summer, to show the regions where such ship noise presently has greatest impact

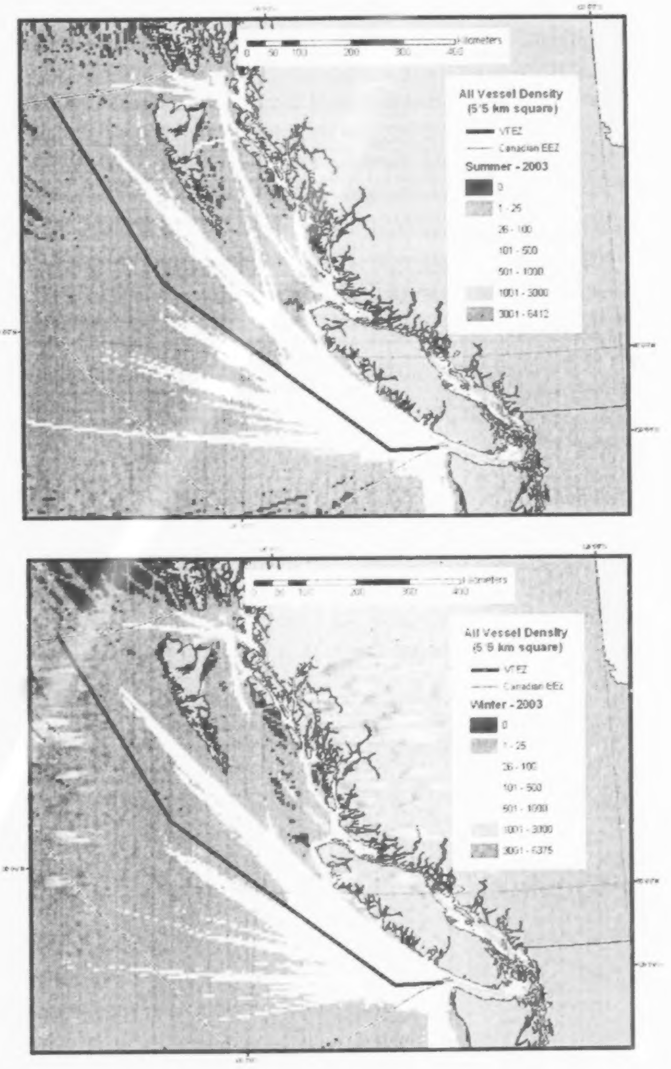

0 50 100 200 300 400 Kilometers
All Vessel Density
(5*5 km square)
VTEZ
Canadian EEZ
Summer - 2003
0
1 - 25
26 - 100
101 - 500
501 - 1000
1001 - 3000
3001 - 6412
0 50 100 200 300 400 Kilometers
All Vessel Density
(5*5 km square)
VTEZ
Canadian EEZ
Winter - 2003
0
1 - 25
26 - 100
101 - 500
501 - 1000
1001 - 3000
3001 - 6375

Figure C.31 Ship traffic density for large commercial vessels during the winter and summer of 2003. The dark black line is the Voluntary Tanker Exclusion Zone (VTEZ). Note the increase in summer traffic in the Queen Charlotte Sound and Hecate Strait (Image courtesy of Patrick O'Hara, Institute of Ocean Sciences, data from Marine Communications and Traffic Services).

8.3. Acoustic Propagation Modelling

In order to predict the behaviour and affects of sounds in the marine environment, numerical models are developed and customized to the characteristics of a given area. In recent years, research groups at the University of Victoria and the Institute of Ocean Sciences have been working on modern models for BC's coastal waters. These models are still in the development stages and are hampered by gaps in data that would help characterize local acoustic conditions. The most significant of these data gaps is the lack of acoustic characterization of the sea floor for much of BC's continental shelf including PNCIMA.

8.4. Noise in the Ocean

Ocean noise is commonly divided into anthropogenic and natural noise, as illustrated in Figure C.32. Anthropogenic noise includes such things as marine traffic, mineral extraction, seismic exploration, marine and coastal construction and other marine activities. Currently marine traffic is the most significant of these in the PNCIMA area. Natural noise includes noise caused by wind, rain, waves breaking, bubble production and breaking, vibrations in the earth, and the noises made by various biota such as marine mammals, fish, and shellfish.

Figure C.32 illustrates the intensity and frequency of various natural and anthropogenic sounds in the ocean. Marine mammal sounds are more studied than most marine species and Richardson *et al.* (1995) have tabulated information from a number of studies. However, it is estimated that only about 0.5% of marine species have been studied (National Research Council 2003). In addition, the hearing range of these species is usually estimated based on the assumption that their hearing range will be similar to their vocalization range. Figure C.33 shows the estimated hearing ranges largely based on this assumption.

The sound environment of the PNCIMA is poorly understood and requires further *in situ* studies and work on modelling, bottom type definition, and subsequent model testing and verification in order to predict the effects of various activities in this area. Further research is also needed to determine the effect on biota of various sound frequencies and intensities before appropriate management decisions can be made.

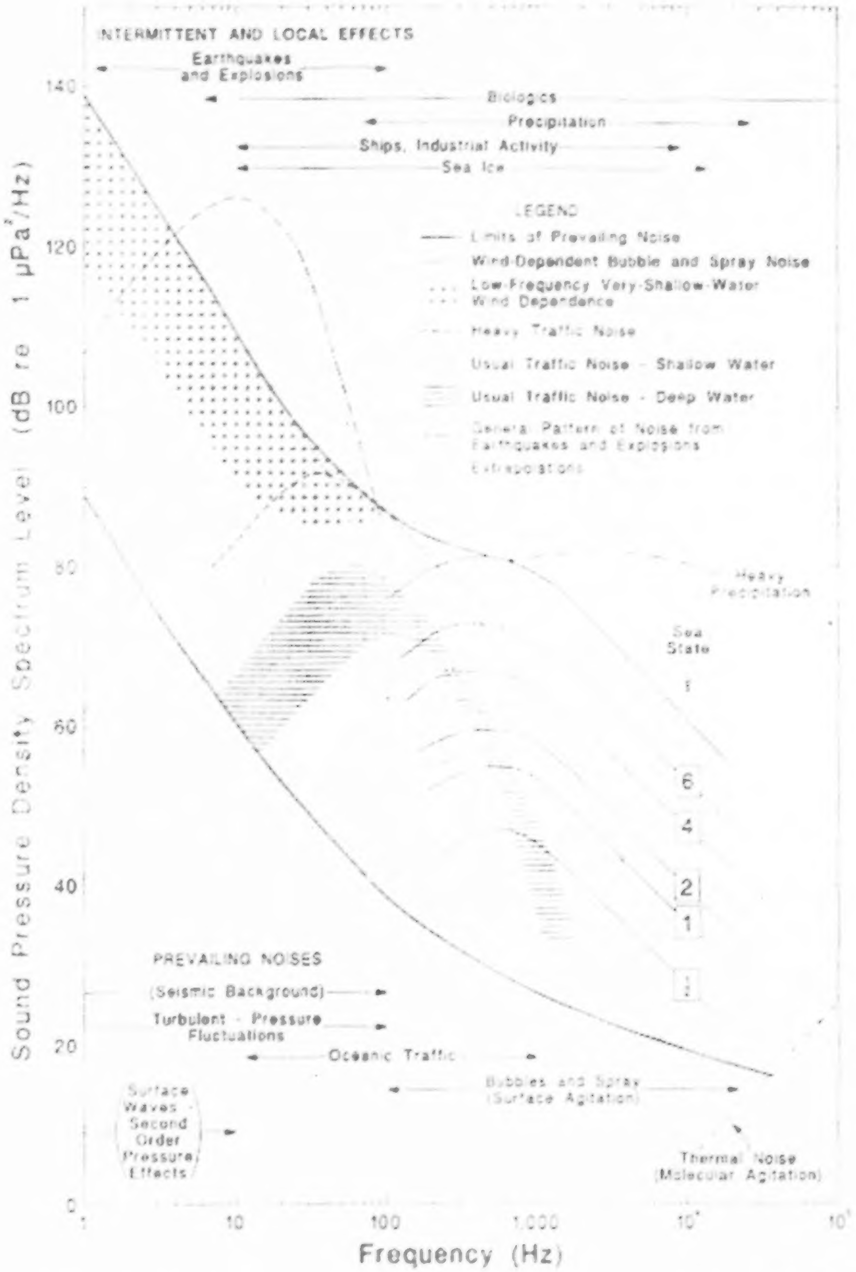


Figure C.32 Ambient noise spectra attributable to various sources (from Richardson *et al.* 1995; based on data from Wenz 1962).

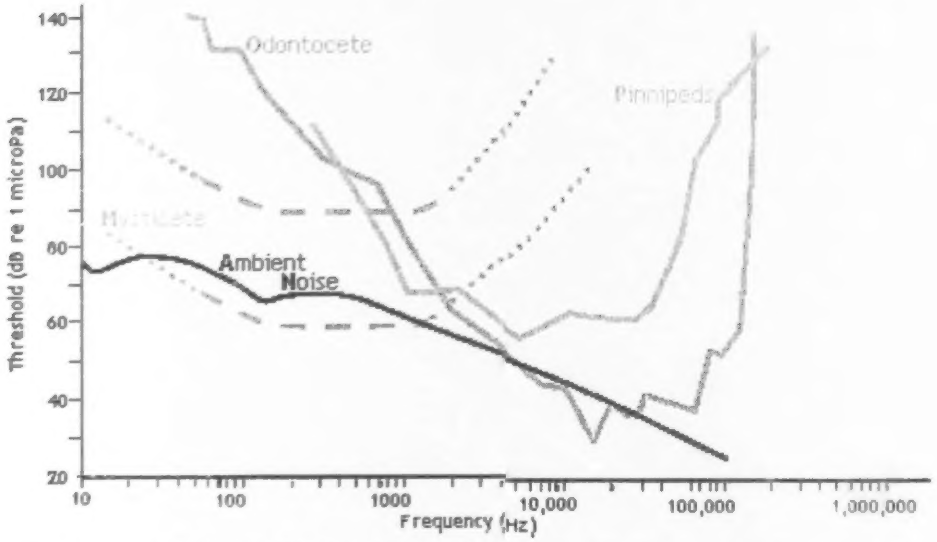


Figure C.33 Estimates of the hearing thresholds for some groups of marine mammals along with estimated ambient noise resulting from sea state. Note that the Mysticete range is based on a mathematical model and the Odontocete and Pinniped lines are minimum thresholds based on a composite of measurements (figure from University of Rhode Island 2003; adapted from Office of Naval Research 2001).

9.0 GLOSSARY

Advect – The horizontal mass movement of a fluid.

Anoxia – Zero oxygen.

Anti-cyclonic – Rotate clockwise.

Attenuation – The total light lost from a beam of light propagating through water. The amount of attenuation is primarily dependent upon the wavelength of the propagated light, the concentration of suspended materials and the concentration and composition of both particulate and dissolved absorbing materials.

Baroclinic – A baroclinic flow is due to density differences of seawater in the ocean.

Coriolis force – This "force" is invoked to explain why ocean currents turn to the right in the Northern Hemisphere. It is a concept similar to that of centrifugal force.

Dissolved oxygen – The amount of oxygen gas dissolved in a volume of liquid. Aquatic animals' uptake dissolved oxygen, and therefore the health of aquatic ecosystems depends very heavily on having sufficient dissolved oxygen available.

Diurnal – A daily cycle. Diurnal tides consist of only a single high and a single low tide occurring every day.

Entrainment – Usually denotes a surface current missing deeper, denser waters up to the surface missing these two water masses together, and carrying the mixed water along in the flow.

Estuarine circulation – The process in which runoff-driven currents in the summer carry surface waters out of coastal inlets, resulting in a counter-current of deeper ocean water flowing shoreward over the shelf along the deep troughs and into inlet basins in the PNCIMA area. Surface flows are fresher; deeper flows are saltier and generally richer in nutrients.

Euphotic zone – The upper layer of water where light penetrates and photosynthesis occurs.

Fetch – The distance a wind blows over the ocean to build up waves. Longer fetches lead to higher waves.

Fjord - A long deep inlet with fresh water entering at its head and flowing seaward to its mouth. Usually a shallow region called a sill is found at the mouth of fjords, where ice-age glaciers deposited sediments thousands of years ago.

Hypoxia – Oxygen levels low enough to affect marine organisms. A common definition of hypoxia is 1.4 ml O_2 l^{-1}, although many organisms are stressed at much higher concentrations and some can tolerate lower concentrations.

Inertial currents – Currents not accelerated by any force.

Inertial period – Periods or episodes where no accelerated force is applied.

Isopycnal – A subsurface layer I the ocean of constant water density.

Katabatic winds –Winds that flow down, in this case down out of the Coast Mountains and seaward over the inlet.

Meridional - A direction that is parallel to a line of longitude; along a meridian; northerly or southerly; as opposed to zonal.

Semi-diurnal – Occurs twice daily. Semi-diurnal tides consist of two highs and two lows each day.

Thermocline – The depth or boundary at which the ocean temperature starts decreasing rapidly with depth.

Vorticity – The measure of fluid rotation.

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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX D: PLANKTON

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1.0 INTRODUCTION

The organisms grouped as 'plankton' are extremely diverse in both body size and taxonomic range. Although most plankton are small in individual size, they are extremely abundant numerically, have high physiological and population turnover rates (growth, metabolism, and mortality), and play key roles in marine ecological and biogeochemical balances, both local and global. Their shared characteristic is low swimming speed compared to the horizontal drift velocities imposed by ocean currents (the word 'plankton' comes from the Greek word 'planktos', for 'wanderer'). This does not mean that their motility is unimportant. Swimming (especially upward or downward across vertical gradients of horizontal flow) and buoyancy/sinking are primary mechanisms for producing vertical and horizontal spatial aggregations (plankton patchiness). These aggregations are important for the feeding success of species that prey on plankton (Strickland 1983).

Plankton are usually sub-classified into three groups: phytoplankton, zooplankton, and bacterioplankton. This classification predates modern molecular phylogeny, but still remains broadly useful in terms of size and ecological function. Phytoplankton are microscopic and photosynthetic. They convert the sun's energy and inorganic carbon and nutrients into organic compounds and particles that provide most of the food for the rest of the marine food web. Zooplankton are slightly-to-considerably larger than the phytoplankton, and eat phytoplankton, bacterioplankton, and other zooplankton. The larger metazoan zooplankton are important prey for many species of fish, birds, and baleen whales. In addition, many fish and benthic invertebrates spend the earliest part of their life cycles as temporary members of the zooplankton. Bacterioplankton are dominant in the "decomposer" part of the pelagic food web, recycling and repackaging non-living organic matter and releasing nutrients back into the water for subsequent uptake by the phytoplankton.

Although limited in coverage, available data suggests that Pacific North Coast Integrated Management Area (PNCIMA, Figure D.0) averages of plankton standing stock, species composition, and turnover rates are broadly similar to other cold-water nearshore regions in the Northeast Pacific, including adjoining areas such as the west coast of Vancouver Island and the Strait of Georgia. Some extrapolation from past research outside PNCIMA is possible and useful. However, important differences are also likely, especially in the degree of coupling between planktonic and benthic components of the ecosystem, amount of exchange between nearshore and open ocean regions, and the details of seasonal and interannual variability.

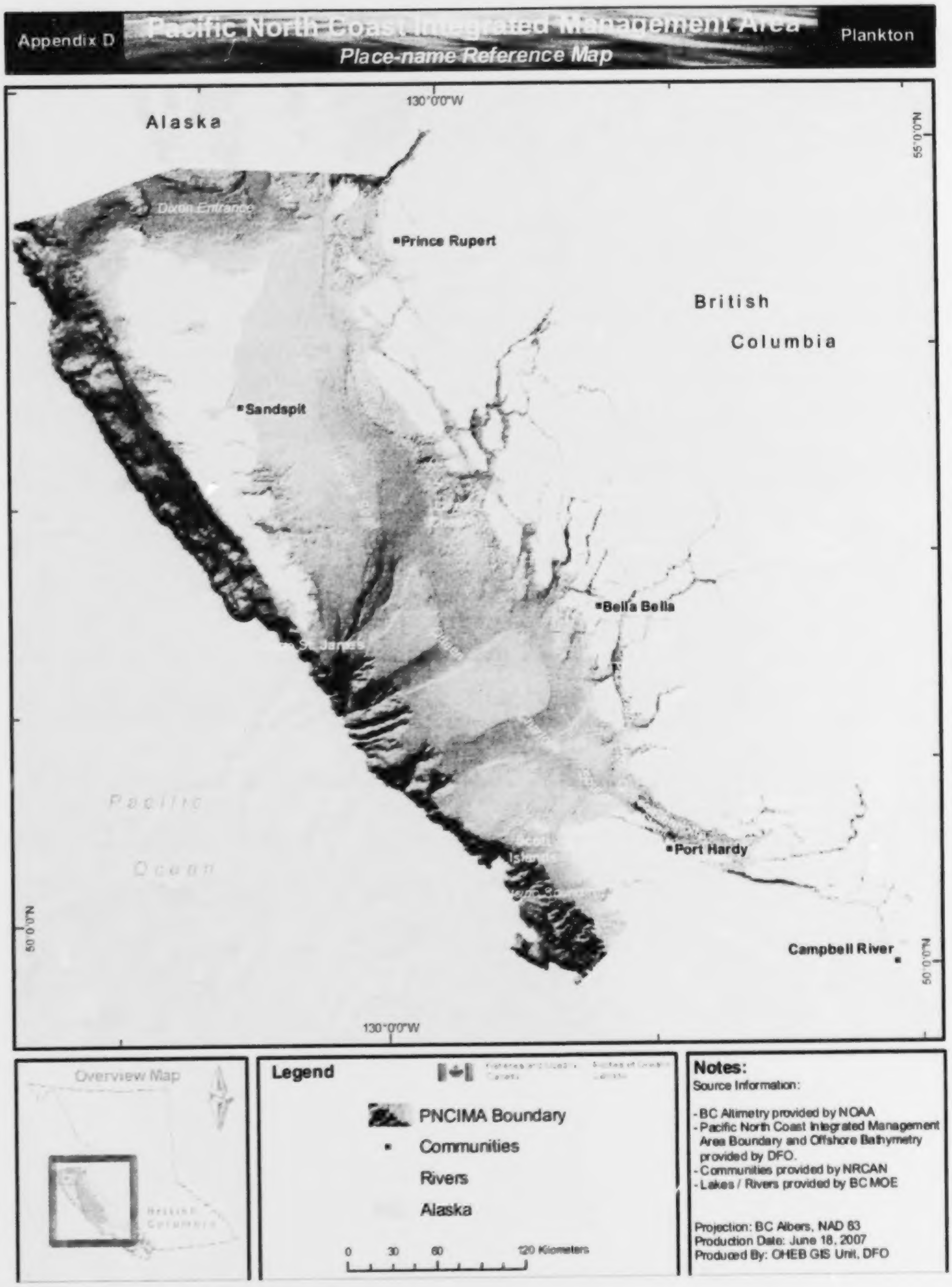
Appendix D
Pacific North Coast Integrated Management Area
Place-name Reference Map
Plankton
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Dixon Entrance
Prince Rupert
British Columbia
Sandspit
Bella Bella
St. James
Pacific Ocean
Port Hardy
Campbell River
Overview Map
Legend
PNCIMA Boundary
Communities
Rivers
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure D.0 PNCIMA region showing locations and features of BC waters.

Recent theory known as the 'Bakun Triad'(summarized by Bakun 1996) says that biologically productive pelagic habitats frequently (perhaps always) contain sub-regions that collectively provide access to three critically important processes:

- food web *enrichment* in the form of high average (or especially well-timed within the year) overall productivity provided by bottom-up nutrient enrichment and plankton productivity,
- localized *concentration* of the productivity from a larger surrounding region, through aggregations of prey that provide high food availability for higher trophic level predators. These patches usually form through advective and/or behavioural convergence of the prey organisms. Aggregation locations are sometimes spatially fixed (especially along bathymetric edges), but can be highly variable (*e.g.*, through meandering of water column currents and frontal boundaries),
- *retention* of critical life stages (often planktonic larval forms) in or near the zones of enrichment and concentration. These situations often occur through enclosure by land or recirculating currents.

The criteria outlined in this 'Bakun Triad' are a useful screening tool for identification of ecologically important areas (EBSAs) and targeting them for enhanced scientific research or protective management.

Because of their place at the base of the food chain, the roles of plankton and their effects on the rest of the ecosystem are very important. Because plankton concentrations and vital rates vary strongly (by factors of 10-1000 or more) over short spatial separations and at time scales ranging from hours to seasonal and interannual, understanding plankton variability, abundance, bloom timing, aggregation (grouping or concentration), and the role of particular species are necessary steps to understanding of ecosystem function and ability to monitor ecosystem health and its reaction to change.

1.1. Key Points

- PNCIMA has had only limited systematic and sustained monitoring of phytoplankton and zooplankton populations, and essentially no monitoring of bacterioplankton. Adjoining coastal regions to the north and south (Strait of Georgia, west coasts of Vancouver Island, SE Alaska, and Washington/Oregon) have been more intensively studied, and cautious extrapolation from these regions is likely to be useful.
- The 'Bakun Triad' of *enrichment*, *aggregation*, and *retention* (Bakun 1996) provides screening criteria useful for delineation of ecologically significant locations within the PNCIMA.
- The broadest coverage of phytoplankton distributions is from satellite images of ocean color. Recent analyses of Sea-viewing Wide-Field-of-view Sensor (SeaWiFS) images indicate moderately high phytoplankton biomass over most of

the continental shelf (the entire PNCIMA area) from the onset of the spring bloom through the summer and into the fall. Very high levels occur at the entrance to some inlets and fjords, though data from these sites may be influenced by suspended sediments in the water.

- New satellite technology may soon make it possible to detect and monitor plankton blooms in small fjords and inlets along the coast. Currently such areas are too narrow for satellites to resolve.
- Zooplankton sampling within PNCIMA has to date been less extensive than in other BC marine waters. McQueen and Ware (2002; 2005) compiled and summarized data collected before 2001. The majority of samples are from 1980 (Fulton *et al.* 1982) and after 1998 (Mackas *et al.* 2004; 2006). Much of the recent sampling (1996-present) has been concentrated in two repeated survey areas (located respectively around the Scott Islands, and in lines across south-central Hecate Strait). The average seasonal cycles in these two areas have similar amplitude and community composition and provide a baseline for future studies of interannual variability. Additional baseline zooplankton data are available for several mainland inlets (details in Section 8.0).
- Aggregations of plankton are critical to the functioning of the marine ecosystem. If plankton were evenly distributed in the ocean, they would be too dilute to support predator species. Maps of zooplankton aggregations both within and outside PNCIMA show that euphausiids (key prey for several finfish and seabirds) aggregate strongly along steep seabed slopes. In PNCIMA, euphausiid aggregations are associated with the three troughs which cut across the shelf in the Queen Charlotte Sound. Northern Hecate Strait and Dixon Entrance are not yet well studied.

1.2. Major Sources of Information or Data:

- A summary of historic (1956-2001) phytoplankton and zooplankton data for much of PNCIMA was compiled by McQueen and Ware (2002; 2005).
- Archived zooplankton and phytoplankton data, including some chlorophyll satellite images, are held by the Ocean Sciences Division of Fisheries and Oceans Canada (DFO) at the Institute of Ocean Sciences (IOS).
- Summaries of plankton information on the scale of the North Pacific can be found in Hood and Zimmerman (*eds.* 1986) and a recent PICES special publication (PICES 2004).
- Brief discussions of plankton in the PNCIMA area can also be found in the aquaculture suitability reports (Ricker *et al.* 1989; Ricker and McDonald 1992; 1995), and the oil and gas related studies of the area (Cretney *et al.* 2002; Chevron Canada Resources Ltd. 1982; Petro-Canada 1983; Jacques Whitford Environment Limited 2001; Strong *et al.* 2002; Hall *et al.* 2004).

- Additional overview information on phytoplankton, zooplankton, and bacterioplankton can be found in Raymont (1980; 1983), and Ducklow (2001) respectively. Useful identification guides include Horner (2002) for the larger phytoplankton, Fulton (1968) for metazoan zooplankton, Wrobel and Mills (1998) for gelatinous zooplankton and Shanks (2001) for meroplanktonic invertebrate larvae.
- Plankton data from 1997 and 2000-present North Pacific Continuous Plankton Recorder surveys are available from the Sir Alister Hardy Foundation for Ocean Science (www.sahfos.org).

1.3. Uncertainties, Limitations, and Variability

- Plankton are highly variable from year to year both in biomass and in species composition. Continuing research is finding that interannual fluctuations are related to decadal scale variations in ocean conditions such as temperature, salinity, stratification, and wind-driven currents. Seasonal variability appears to be relatively predictable given a long enough data set (beginning to be available for parts of PNCIMA).
- Plankton are also highly spatially variable. Extrapolation of averages and ranges based on small numbers of samples leads to high levels of uncertainty.
- Most zooplankton work has been done on the medium to large sized species and life stages (0.7 mm to >1 cm) caught and retained by standard plankton nets. However, this size fraction includes those species most utilized by fish, birds, and baleen whales.
- Much of the interpretation of phytoplankton seasonal and spatial distributions is based on remote sensing data. These need additional validation against *in situ* "sea-truth" measurements.

1.4. Identified Knowledge and Data Gaps

- While the satellite data archive for PNCIMA is expanding steadily, studies involving *in situ* sampling of all types of plankton are few in number and smaller in scope and duration than in other Canadian west coast regions. This tendency increases northwards. For example, the least is known about Dixon Entrance, despite the fact that its physical characteristics (significant estuarine exchange and mixing, and the presence of a circulation gyre and submarine sills which are likely to promote plankton aggregation) may make it very biologically productive.
- Little research has gone into the smaller plankton forms such as nano- and pico-plankton and bacterioplankton. The significance of their role in the ecosystem, and their sensitivity to ecosystem change and anthropogenic effects are not known, except by extrapolation from other ocean regions.

- The identification of critical areas within PNCIMA of plankton *aggregation* and (probably) of peak interaction between planktonic prey and predators has just begun and requires further analysis and confirmation.
- *Retention* of plankton, and especially of meroplanktonic larval stages, is likely to be both ecologically important and highly variable from year to year.

2.0 PLANKTON TYPES AND IMPORTANCE

The term plankton includes a huge variety of organisms ranging widely in size (< 1 μm (micrometer) to > 10 cm), high order taxonomy, and position within the marine food web. This broad grouping is often simplified into three key components: phytoplankton, zooplankton, and bacterioplankton. This classification predates modern molecular phylogeny, but still remains broadly useful in terms of size and ecological function.

The phytoplankton (section 3.0) are photosynthetic autotrophs, and ultimately provide most of the food energy that supplies the rest of the marine food web. Some of this production is released into the water in the form of dissolved organic matter and non-living particulate detritus that is broken down by the microscopic bacterioplankton (section 5.0), which also play a primary role in the recycling and release of the dissolved nutrients used by the phytoplankton. Some bacteria are chemosynthetic autotrophs, fixing organic matter using chemical energy from sea-floor vents and seeps. Both phytoplankton and bacterioplankton (and in some cases particulate detritus) are grazed by heterotrophic zooplankton. The zooplankton include both microscopic single-celled flagellates and ciliates (the microzooplankton), and a wide range of larger metazoan animals (mesozooplankton and macrozooplankton/micronekton). Many zooplankton are also (often primarily) predatory on other zooplankton. Prey selectivity is strongly related to prey size. Although the bacterioplankton are nearly all tiny (most are single cells <1 μm in diameter), the phytoplankton and zooplankton range widely in size and are often further subclassified based on their size as well as on characteristics of form and function (see sections 3.0 and 4.0).

Collectively, the plankton form the base levels of the marine food web. The 'classic' cartoon of the planktonic food web starts with relatively large-celled phytoplankton producing biomass using the energy of the sun; crustacean zooplankton eat these phytoplankton, fish eat the zooplankton, and on up the food chain. The real world is not that simple (see recent reviews such as Vaulot 2001). Often there are competing alternative food pathways, such as the 'microbial loop,' within which much of the total productivity never reaches the large zooplankton or fish, because microbial degradation recycles the organic material to basic nutrients. Also, the variations in timing and species composition of blooms and environmental conditions can redirect productivity to either the benthos or gelatinous zooplankton which can have significant effects on ecosystem function.

While plankton are found throughout the open ocean, plankton productivity is highest along the continental margins where nutrients are more plentiful than further offshore. This results in both a higher abundance of plankton and a higher proportion of the larger sized plankton. The importance of coastal productivity is underlined in recent research which supports the idea that retained plankton productivity directly influences resident fish populations. Ware and Thomson (2005) found significant correlations between annual coastal phytoplankton productivity and fluctuations in fish biomass for large sections of the Pacific coast of North America. Their work shows that, at an ecosystem level, locations with high phytoplankton and zooplankton productivity and biomass can be expected to produce high fish biomass, and vice versa.

3.0 PHYTOPLANKTON

The phytoplankton convert the sun's energy, inorganic carbon, and dissolved nutrients into dissolved and particulate organic matter. In addition to supporting their own biomass and metabolic needs, phytoplankton ultimately provide most of the food for the rest of the marine food web. Globally, the phytoplankton are thought to be responsible for 40% of the photosynthesis on the Earth (Garrison 2002). In the open ocean, this fraction is essentially 100%, and in many coastal ocean areas (including PNCIMA) is >90% (the very near-shore production by benthic macrophytes and seagrasses is greater per unit area, but is depth limited to a very small fraction of the total area). Because of the need for sunlight, high phytoplankton growth rates and biomass are confined to the upper ocean 'euphotic zone'.

Although individually small (microscopic or barely visible to the naked eye), phytoplankton can grow/reproduce rapidly and under some circumstances produce dense blooms that discolour the water. Local rate of growth (and accumulation of biomass) depend on interaction between:

- availability of inorganic nutrients such as N, P, Si, Fe (different subgroups use these nutrients in differing ratios),
- availability of light, which changes with season, and is also affected by turbidity and by density stratification/mixing of the water column (Sverdrup 1953),
- temperature,
- how fast they are eaten (different sizes are captured and eaten by different zooplankton subgroups), and
- sinking losses, which are affected by the "particle size" of the phytoplankton, their nutritional status, and density stratification/mixing of the water column.

In part for this reason, and in part because of differences in sampling and identification methods, the literature often classifies phytoplankton by size, although the classification schemes vary widely among authors. One relatively common format of size differentiation modified from Smith (1977) and Garrison (2002) is:

Macroplankton	Greater than 1 mm	
Microplankton	0.075 mm – 1 mm	75 µm - 1000 µm
Nanoplankton	0.002 mm – 0.075 mm	2 µm – 75 µm
Picoplankton	0.002 mm – 0.0002 mm	2 µm – 0.2 µm

The picoplankton have recently been found to form a very significant portion of total productivity in the open ocean but are proportionately less significant in coastal areas, where larger phytoplankton are often abundant.

Phytoplankton are also classified based on their morphology, phylogenetic status, and physiological/biochemical characteristics. Within PNCIMA, the phytoplankton groups of ecological or geochemical importance include diatoms, dinoflagellates, "phytoflagellates", cyanobacteria, and coccolithophorids.

- Diatoms have cell walls (frustules) made of silica. Taxonomic identification is based on the structure of these frustules. In size, most are nanoplankton or microplankton. They occur as single cells, but also as chains made up of many cells. Both growth rates and nutrient requirements (especially for Si and Fe) tend to be high. Two major groups of diatoms are recognised: the centric diatoms (with radial symmetry), and the pennate diatoms (with bilateral symmetry). Diatoms account for much of the spring and summer season biomass and productivity in PNCIMA (Perry 1984).
- Dinoflagellates have two flagellae (whip-like appendages that help them to move through the water). They usually occur as single cells. Some species are "armoured" by a thick cellulose cell wall which is divided into taxonomically-characteristic plates. Many species lack chlorophyll and are non-photosynthetic, and therefore function ecologically as microzooplankton. In size, most are similar to or slightly smaller than the diatoms, although a few (such as *Noctiluca*) can exceed 1 mm. Several species produce toxins (see section 6.0). Peak abundance in PNCIMA tends to occur in mid-late summer (Perry 1984; Forbes and Waters 1993).
- "Phytoflagellates" are a diverse composite group, crossing ten taxonomic classes of algae. Their shared characteristics are motility and size (small nanoplankton). Identification requires powerful microscopes or biochemical techniques. Phytoflagellates are numerically very abundant and often dominate the phytoplankton in offshore regions and also in winter when larger forms - *i.e.*, diatoms and dinoflagellates - are low in concentration. Thresholds for nutrient limitation tend to be lower than the diatoms.
- Cyanobacteria (including the so-called blue-green algae) are photosynthetic but are a form of bacteria. Most are tiny single cells <1 µm in diameter (picoplankton) but a few clump together to form "bundles" that can be seen by eye. Some cyanobacteria can fix nitrogen from the atmosphere. Although

minute, they occur in large numbers and are major contributors to oceanic productivity, especially in open ocean areas. One type, *Prochlorococcus*, may be the most abundant species on earth.

- Coccolithophorids are an interesting and important sub-group within the phytoflagellates. They surround themselves with scales called coccoliths that are made of calcite. Single coccolithophorids are commonly smaller than 20 μm across and are often enclosed by over 30 plates. When they produce dense blooms, they turn the water a milky turquoise color. Their calcite production affects surface alkalinity, with important consequences for air-sea exchange of the greenhouse gas CO_2.

Phytoplankton blooms are not always beneficial. "Unused" blooms can crash after they run out of nutrients, and sink and decay, producing hypoxia in subsurface waters. Some kinds of phytoplankton produce toxins (or other irritants) that harm fish and mammals (section 6.0).

As noted above, phytoplankton thrive and grow when and where there is a combination of sufficient intensity and duration of daylight (spring and summer in high latitudes), penetration of the sunlight sufficiently deep into the water column to reach the phytoplankton (high concentrations of suspended sediments obstruct this; strong vertical mixing can move the phytoplankton below the sunlit layer), and sufficient availability and resupply of dissolved inorganic nutrients (especially N, P, Si and Fe). Land-derived micronutrients (especially iron) strongly limit the amount and taxonomic composition of phytoplankton in many open ocean areas, including the oceanic subarctic Pacific. However, in continental margin areas such as PNCIMA, nutrient limitation is primarily by the macronutrients (N, P) supplied from deep water by a combination of upwelling, tidal and wind mixing, and estuarine entrainment (see Appendix C: Physical and Chemical Oceanography).

Light-harvesting pigments in the phytoplankton give them their distinctive colours, and the green colour and fluorescence of the dominant pigment, chlorophyll, allows phytoplankton to be detected remotely by satellites. Satellites are useful tools for determining phytoplankton concentrations over large scales, although the interpretation of the images requires ground-truthing because the satellite data can be affected by high turbidity waters (falsely high chlorophyll indicated in areas of high suspended sediment concentrations).

Optimal conditions for plankton blooms in high latitude regions are often quite seasonal. During the winter there is insufficient daylight and storms mix the ocean too deeply to allow significant build-up of phytoplankton; levels of chlorophyll are generally less than 1 mg m^{-3}. The mixing that inhibits winter productivity is useful later in the year, however, as it brings deep nutrients to the surface. In spring, light and temperature increase and winds weaken sufficiently to cause stratification of the surface waters allowing the spring plankton bloom (Sverdrup 1953). This bloom continues until nutrients are depleted. In the waters over the continental shelf, the bloom is generally stronger and can last much longer if there is a supply of new nutrients.

Information on spatial and seasonal distributions of phytoplankton biomass and productivity within PNCIMA is now available from a 5-year time series (September 1997 to October 2003) of chlorophyll concentration measured at ~1.1 km resolution by the SeaWiFS color satellite (Peña and Crawford 2004). In terms of the 'Bakun Triad', the temporal and spatial patterns primarily reflect the distribution of 'enrichment', plus, in some cases, of 'retention'. Figure D.1 shows the number of months between spring and early fall from 1997 to 2003 for which chlorophyll levels at each location exceeded 3 mg m^{-3}. Several areas around the perimeter of the basin sustain high phytoplankton biomass throughout much of the spring, summer and fall. These areas have large and sustained nutrient supply either from freshwater river runoff and deep-water entrainment, from strong tidal mixing in shallow areas, or from wind-driven upwelling in the summer. Some of the 'chlorophyll' in all these regions may be contributed by color from suspended sediments.

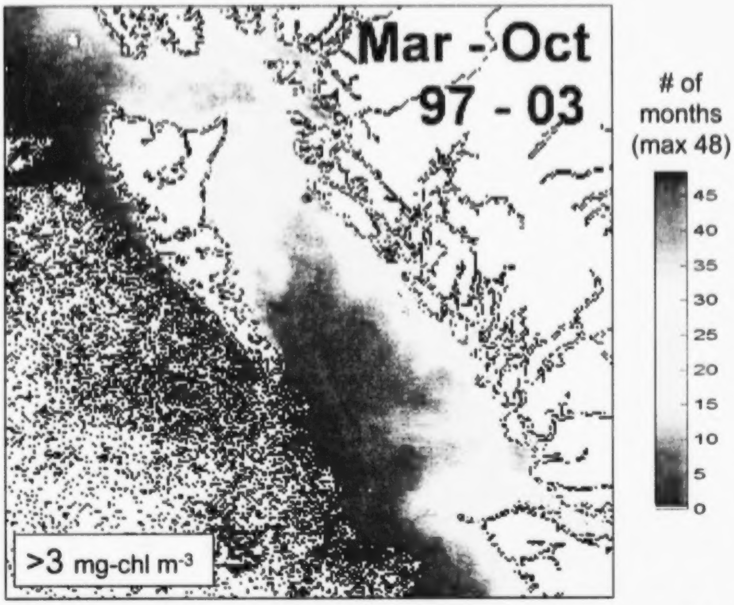

Figure D.1 The number of months a given pixel contained chlorophyll levels over 3 mg m^{-3} from March to October from 1997 to 2003 (from Peña and Crawford 2004).

In addition to these hotspots, most of PNCIMA remains relatively productive from spring through to fall (Figure D.2). However, chlorophyll concentrations are usually low near Cape St. James, the region with strongest vertical mixing by tidal currents, due to the combined effects of strong horizontal advection, strong vertical mixing, and lack of vertical stratification (all leading to poor retention of biomass). The spatially-averaged seasonal cycle shows peak chlorophyll concentration in May (average 5 mg m^{-3}) but relatively high concentrations (~ 3 mg m^{-3}) persist from June through early fall. This contrasts with many other high latitude ocean regions, in which the spring peak is followed by relatively low biomass and productivity through the summer.

Phytoplankton community composition varies seasonally in PNCIMA. Small flagellates dominate the relatively low winter phytoplankton productivity and biomass. Diatoms dominate in the spring. Many are from the genera *Chaetoceros* and *Thalassiosira,* (Perry 1984) shown in Figure D.3. In the summer, a variety of flagellates numerically dominate (*e.g.*, *Ceratium* spp., Figure D.3 and *Imantonia rotunda*), but diatoms (*e.g.*, *Leyanella arenaria*) continue to dominate the biomass (Forbes and Waters 1993; Perry 1984). In fall and winter, the diatom contribution drops below 50%.

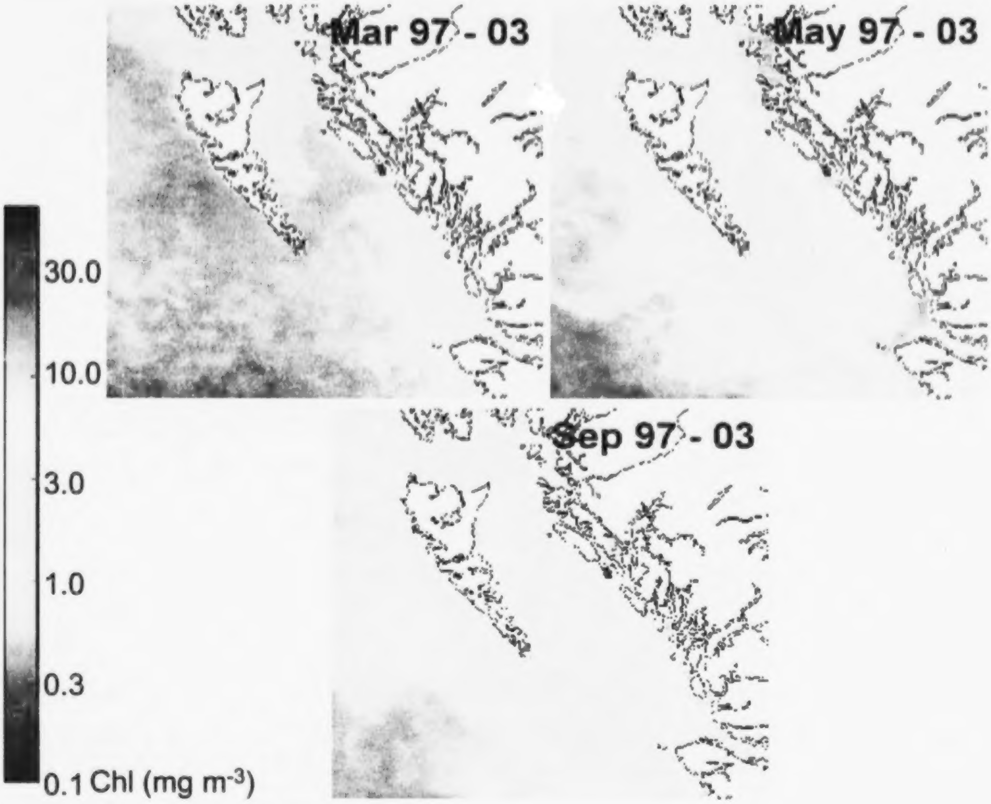

Figure D.2 Aggregated monthly averaged satellite chlorophyll data from 1997 to 2003 for March, May and September. Data reveal bloom hotspots but also the fact that the shelf is quite productive (>1 mg m^{-3}) from March through to September and even into October (from Peña and Crawford 2004).

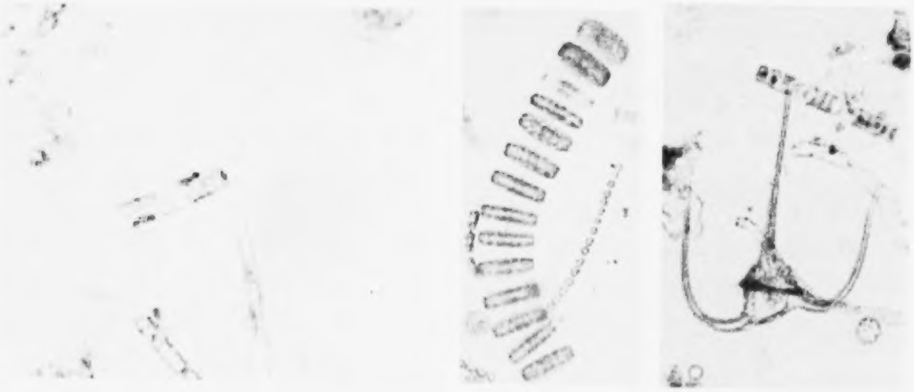

Figure D.3 Two diatoms *Chaetoceros* (left) and *Thalassiosira* (centre) and the dinoflagellate *Ceratium* spp (right) ~0.3 mm long; with a diatom in the upper right (Monterey Bay Aquarium Research Institute 2006).

The interannual variability of PNCIMA phytoplankton biomass is currently being analyzed (Peña and Crawford unpublished data). The strongest interannual variation occurs in spring, and is due to changes in the height and onset timing of the initial spring bloom. To date, the highest measured chlorophyll concentrations (>15 mg m^{-3}) were observed in spring of 2002 during a "cool" ocean regime in the NE Pacific.

4.0 ZOOPLANKTON

Zooplankton include a wide range of animals (LeBrasseur and Fulton 1967). Some are planktonic only in their larval stage (meroplankton such as clams, crabs, barnacles and fish larvae), while others (holoplankton such as copepods, euphausiids and other crustaceans, jellyfish, chaetognaths, and pteropods) remain planktonic throughout their entire life cycle. A common classification of zooplankton combines aspects of their size, morphology, diet, and motility. From smallest to largest, these classes are:

- *Microzooplankton*, made up of unicellular flagellates, ciliates and protozoans, plus early life stages of the smaller mesozooplankton. Most of the grazing of bacterioplankton and of the smaller phytoplankton is by microzooplankton. There is phylogenetic overlap between some unicellular microzooplankton and phytoplankton groups; the distinction is whether or not they obtain most of their food energy from their own photosynthesis or by feeding on other organisms. Life cycles and population turnover times are short (~0.5-2 days), and changes in population tend to closely track changes in productivity of their prey. This group is sometimes subdivided into microzooplankton including ciliates and non-photosynthetic dinoflagellates and nanozooplankton including much smaller nanoflagellates of 0.002-0.005 mm.

- *Mesozooplankton.* This is the subgroup most easily sampled with conventional plankton net tows. They are multicellular, range in length from about ~0.5-10 mm, and feed on larger phytoplankton, microzooplankton, and other mesozooplankton. Abundance and biomass are often dominated by 'herbivorous' calanoid copepods (Figure D.4), but this group also includes chaetognaths, juvenile euphausiids, pteropods, and amphipods, and meroplanktonic larvae of benthic species. Life cycles range from weeks to annual, and on average the peaks of mesoplankton biomass occur after and for a longer duration than individual phytoplankton blooms. However, year-to-year variations in timing match-mismatch between phytoplankton productivity, zooplankton life history timing, and predator demand can be an important control of ecological transfer efficiency. Swimming ability is sufficient to give full control of vertical position, and vertical distributions are usually strongly layered. The depths of these layers vary among species but also with time; many species carry out daily and/or seasonal vertical migrations over 10s-100s of meters. The primary evolutionary cause for the vertical migration is thought to be avoidance of predators or unfavourable upper ocean environmental conditions. The migrations also interact with depth gradients of the speed and direction of ocean currents to produce horizontal aggregation and retention.

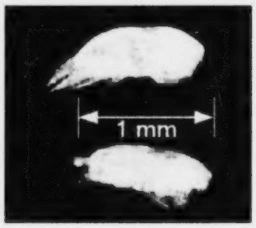

Figure D.4 *Paracalanus* and *Pseudocalanus* copepods. Source: http://darwin.bio.uci.edu/~jzamon/JenZ_Research.htm.

- *Macrozooplankton* (also called micronekton) are larger than the mesozooplankton (generally between 1 and 6 cm) and have stronger swimming, sensory, and net avoidance capabilities. Examples include adult euphausiids (krill), pelagic shrimps, heteropods, plus larval and small adult mesopelagic fish and squids. Diet consists of mesozooplankton and (for some species) large phytoplankton. Life cycles are mostly annual in our latitude range, but can be multi-year. Diel vertical migration of ~100 m or more is common, and is important for prey-predator interaction, spatial aggregation, and retention. The euphausiids have very patchy distributions, and there are localized areas with very large euphausiid biomass in all BC waters including PNCIMA (Figure D.8). In part because of their tendency to aggregate, euphausiids are key prey items for many fish, seabirds and some baleen whales.

- *Gelatinous zooplankton* can be as large as or larger than macrozooplankton but have 'watery' bodies with lower nutritional value per unit volume, and weaker swimming and net avoidance abilities. The gelatinous zooplankton includes cnidarians (hydromedusae, scyphomedusae, colonial siphonophores) and ctenophores. The medusae and ctenophores are primarily or exclusively carnivorous on other zooplankton. In addition, the gelatinous zooplankton include planktonic urochordates (salps, dolilids, and larvaceans), which use mucus feeding webs to strain both small and large particles (picoplankton to mesozooplankton) from the water. Reproductive and somatic growth rates can be rapid, leading to quick appearance and disappearance of conspicuous gelatinous zooplankton 'blooms'.

The various metazoan zooplankton (meso-, macro-, mero-, and gelatinous) differ from the unicellular microzooplankton, phytoplankton and bacterioplankton (and resemble fish and benthic invertebrates) in one additional important way. The larger zooplankton all have multistage life cycles, with the different stages often differing drastically in size, diet, vertical distribution, seasonal timing of peak abundance, and vulnerability to predators and/or specific physical environmental conditions. Most mid- and high-latitude species have evolved strongly seasonal life history strategies that optimize the probability of reproductive success and survival of successive life stages. But this seasonal specialization also makes them vulnerable to serious timing mismatch whenever environmental seasonality is anomalous.

Fisheries and Oceans Canada hosts a website (http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/plankton/zooplankton/default_e.htm) that provides photographs and basic ecological information on the zooplankton most common in BC waters. Most of the DFO zooplankton research off the coast of BC has focussed on the meso (about 0.7 mm to 1 cm) and macrozooplankton (>1 cm) both because different methodologies are used to study the microzooplankton, and because the larger plankton form the diet of so many predator species.

PNCIMA is less rich in zooplankton data than other BC regions. McQueen and Ware (2002; 2005) summarized data collected before 2001, however the majority of samples in the McQueen and Ware compilation are either from 1980 (Fulton *et al.* 1982) or from after 1990 (Mackas *et al.* 2004; 2006). Recent sampling (1996-present) has been concentrated in two repeated survey areas located respectively around the Scott Islands, and in lines across south-central Hecate Strait (Figure D.5). Additional (and older) baseline zooplankton data are available for some mainland inlets (Section 8.0).

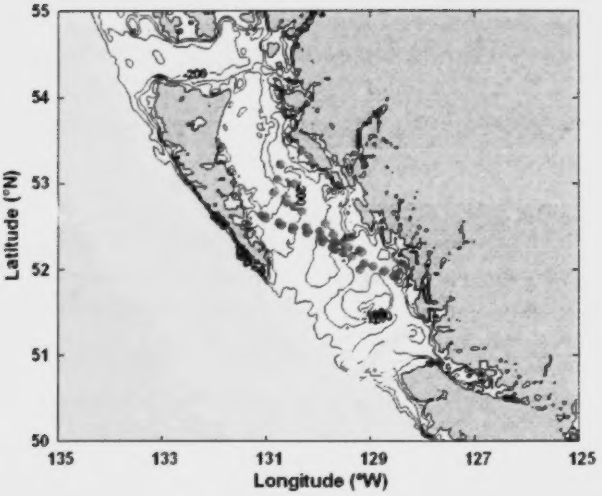

Figure D.5 Two regions within PNCIMA where zooplankton net tow sampling has been frequent since the mid-1990s: surrounding the Scott Islands (orange dots, 1990 and 1996-present), and transects across southern Hecate Strait (red dots, 1998-present).

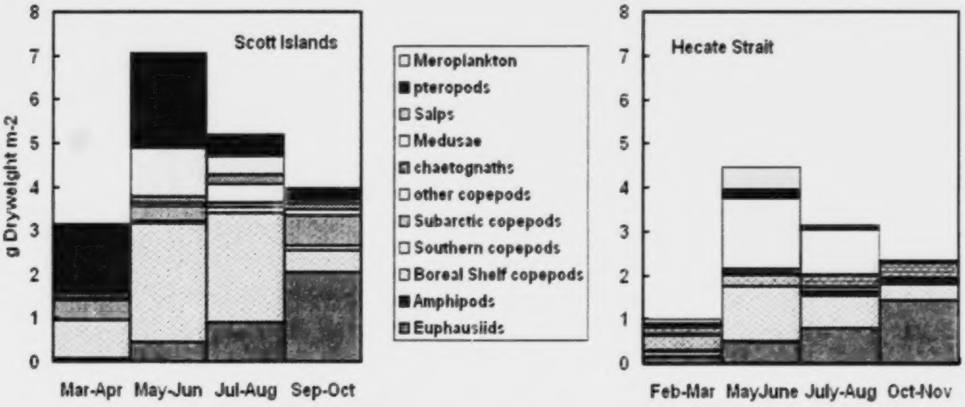

Figure D.6 Multi-year average seasonal cycles of mesozooplankton biomass and community composition for the areas shown in Figure D.5.

Average seasonal cycles for the Scott Islands and southern Hecate Strait regions (Figure D.6) have amplitudes and community composition that are similar to each other, and also to the continental shelf of southern Vancouver Island, where similar monitoring has been carried out for many more years. In all of these regions, winter zooplankton densities, like that of phytoplankton, are at an annual minimum. Small to medium-sized copepods tend to be the most common zooplankton (Perry 1984; LeBrasseur and Fulton 1967). Although they are not as numerous as the copepods, euphausiid biomass can be fairly high in late fall and early winter due to their relatively large body size and prolonged individual life span. In spring, many of the mesozooplankton spawn, and total numbers follow the upward trend in the phytoplankton population with a short time lag. The copepods continue to numerically dominate the zooplankton population with densities reaching thousands of copepods per cubic meter. The copepod genera *Pseudocalanus*, *Calanus*, *Neocalanus*, *Acartia*, and *Oithona* are all locally abundant during springtime. The life cycles of the (oceanic) *Neocalanus* spp. includes an obligatory and prolonged dormant period spent at depths from 300 to >1000 m. Their spatial distribution in the PNCIMA is therefore confined to the deeper locations, and their presence in the surface layer is confined to a relatively few months in spring and early summer. However, during this period their biomass is very large and they are important prey items for fish, whales and seabirds. Many of the larval invertebrate meroplankton are also most abundant in the springtime. From summer into autumn the *Neocalanus* migrate downward from the surface layer, and the remaining mesozooplankton copepods are dominated by *Calanus*, *Pseudocalanus*, *Oithona* and *Metridia*. Euphausiid biomass reaches a maximum in autumn in most locations (Mackas *et al.* 2004).

Compared to the continental margin off Vancouver Island (both south and north), Hecate Strait has lower total biomass (by 1.5-3x), smaller amounts of deep-water oceanic species (pteropods, subarctic oceanic copepods, salps), and larger amounts of meroplanktonic larvae. These developing PNCIMA time series and averages will provide a baseline for future studies of interannual variability.

The seasonal cycle of zooplankton availability is certainly important to animals that eat zooplankton. However, a plot (Figure D.7) of biomass in individual samples vs. date within year provides a useful reality check on what controls the distribution and success of plankton predators. The within-region, within-season variability is typically a factor of 10-30 (*i.e.*, 3-5 fold larger than the amplitude of 'average' seasonal cycle). Part is caused by spatial patchiness, part by interannual variability.

Although very intense, the patchiness of zooplankton off the central and northern BC coast does not appear to be closely tied to the location of phytoplankton blooms (compare Figures D.8 and D.2). As noted in section 3.0, most of PNCIMA has high phytoplankton biomass from spring through fall. Food availability for herbivorous zooplankton may therefore be broadly adequate throughout PNCIMA for much of the year. Especially for larger zooplankton such as euphausiids, control of aggregation location and intensity appears to be by interactions between currents, bathymetry, and zooplankton swimming and vertical migration behaviour. We now know (from research in PNCIMA and elsewhere) that high euphausiid biomass is often found over steep sea floor slopes (Simard and Mackas 1989; Mackas *et al.* 1997; Simard and Lavoie 1999; Mackas *et al.* 2003). In PNCIMA, these locations include the continental slope, and also the margins of the deep troughs leading from the outer coast into Queen Charlotte Sound. Both are also zones of high fish catch (see Appendix G: Groundfish); it is unlikely that this overlap in distribution is coincidental.

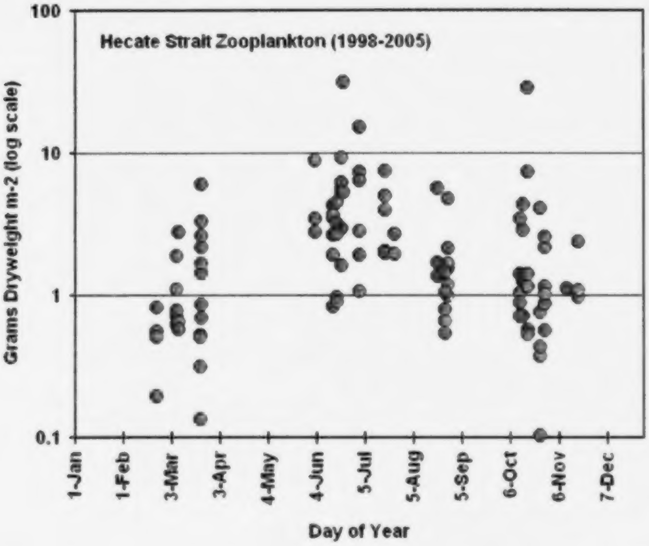

Figure D.7 Biomass in individual samples used to calculate the Hecate Strait seasonal cycle. Large variability around the average annual cycle is added by spatial patchiness and interannual differences.

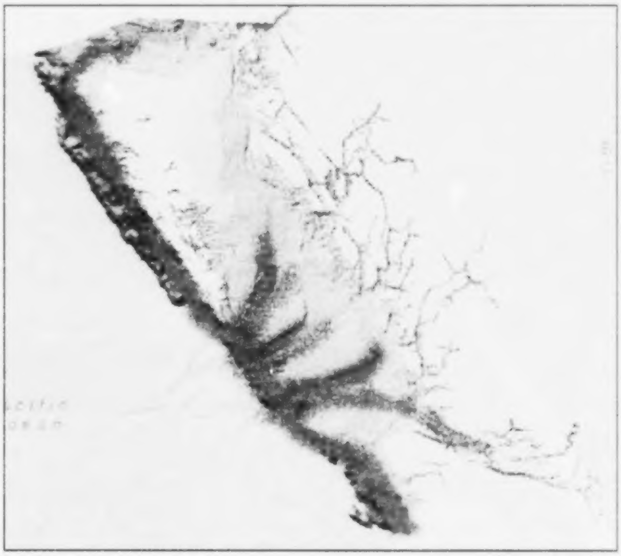

Figure D.8 Known and predicted zones of euphausiid aggregation in open water parts of PNCIMA (additional smaller scale aggregations occur in many inlets). Map is based on net tow and acoustic sampling of the BC coast (Simard and Mackas 1989; Fulton *et al.* 1982; Mackas *et al.* 1997; 2006).

Abundance of larval fish (icthyoplankton) is for most species greatest in winter and spring. This timing is quite significant because wind-driven advective displacement of surface water can be large in winter, and poor retention of larvae within coastal waters may significantly limit the abundance of adult fish in subsequent years. The recruitment of Pacific Cod stocks has been correlated with this wash-out phenomenon, showing improved stock size following milder winters (Tyler and Crawford 1991). In addition to this, one or two large Haida Eddies form off Cape St. James in most winters and move offshore in spring and summer, where they decay over the next few years. The Haida Eddies tend to be larger during winters that have stronger poleward winds. They transfer large amounts of shelf/slope waters, including the plankton community members. Plankton species from slope waters often persist longer within the eddies than those from shelf waters (Crawford *et al.* 2003; Mackas and Galbraith 2002a; DFO 2002).

5.0 BACTERIOPLANKTON

Although some of the fundamental research on bacterioplankton was done in BC south coast waters and at Ocean Station P (*e.g.*, Fuhrman and Azam 1980; Hollibaugh *et al.* 1980; Albright 1983; Kirchman 1990; Sherry *et al.* 1999), bacterioplankton have received little study in PNCIMA (Chevron Canada Resources Ltd. 1982; Atlas and Griffiths 1986). Understanding of their importance in marine ecosystems has grown over recent years with advances in analytical techniques (Ducklow 2001). Bacteria are ubiquitous in the marine environment and their productivity is thought to be on the same order as that of phytoplankton (Petro-Canada 1983). Their primary roles in the ecosystem include conversion of dissolved organic compounds to living and non-living detrital particulates, and the breakdown of organic matter into its component nutrients. This circuit of material (particularly carbon and nitrogen) from organic to mineralized and back again via microscopic organisms is called the 'microbial loop' (Garrison 2002; Petro-Canada 1983) and is active in all marine environments. The presence of bacteria on detrital particulate matter is also thought to increase the nutritional value of these particles for organisms higher in the food web. There is also a very active interaction between the bacterioplankton and the even smaller marine viruses (Suttle 1994), with viruses now known to cause much of the total bacterial mortality through infection and lysis.

The bacterial genera found most broadly in the marine environment include *Micrococcus*, *Sarcina*, *Bacillus*, *Vibrio*, *Bacterium*, *Pseudomonas*, *Corynebacterium*, *Spirillum*, *Civoplana*, *Nacardia*, and *Streptomyces*. Forms able to cause human disease occur near untreated sewage discharges, but in general survive poorly in cold ocean water. Bacterioplankton are also involved in some fish diseases (see Appendices F, G, H and I). There is no current evidence that any portion of the BC coast is more or less susceptible to these pathogens than the rest. Finally, some bacteria, known as olioclastic bacteria, degrade petroleum hydrocarbons (Leahy and Colwell 1990). These bacteria are likely to be present in PNCIMA and may even be abundant near the natural oil seeps known to be present (Hall *et al.* 2004).

6.0 TOXIC BLOOMS

Some species of plankton produce harmful toxins that can accumulate in filter-feeding shellfish and other organisms. The first case of Paralytic Shellfish Poisoning (PSP) in PNCIMA was first documented by Europeans in 1793 when Captain Vancouver's ship visited Mathieson Channel (Vancouver 1984). PSP has continued to be a significant problem on the BC coast (Jamieson 1986). More recently Diarrhetic Shellfish Poisoning (DSP) and Amnesic Shellfish Poisoning (ASP) have been detected and recognized as potential human health concerns (Taylor and Harrison 2002).

PSP in BC waters is largely caused by the dinoflagellate *Alexandrium catenella* (Figure D.9) which produces a saxitoxin that bioaccumulates in bivalves and can be fatal when affected shellfish are ingested by humans (Taylor and Harrison 2002; Horner 2001). No antidote is available. The BC/Alaska coastline has been identified as possibly the world's worst PSP problem area. In Alaska, at least one person dies each year from eating PSP-contaminated shellfish. In BC, since monitoring and record keeping began in 1942, each year has had some portion of the coast test positive for toxicity. Reddish discoloration of the water, known as "red tide", is not necessarily synonymous with PSP. *Alexandrium catenella* tainted waters are only sometimes the colour of weak tea, or rusty-red. Another dinoflagellate, *Noctiluca* (named for its bioluminescence), produces tomato-soup like water, and is non-toxic, although it does produce ammonia that can be stressful to fish (Ricker and McDonald 1995).

Figure D.9 *Alexandrium catenella* the 'red tide' dinoflagellate (photo by Jan Rines jrines@gso.uri.edu).

Several species of *Pseudo-nitzschia* produce the toxin (domoic acid) responsible for ASP, including *P. multiseries, P. pungens, P. australis, P. delicatissima and P. pseudodelicatissima* (Horner 2001). *Pseudo-nitzschia* is present and often abundant in BC waters in the summer and fall. Off Vancouver Island, it is usually most abundant over the outer continental shelf (Taylor and Harrison 2002), but high abundances were observed in samples from central Hecate Strait in summer of 1983 (Forbes and Denman 1991). Outbreaks in BC and Alaska tend to be preceded by outbreaks to the south, providing some warning time.

DSP has been linked to species of the dinoflagellate genus *Dinophysis* (Taylor and Harrison 2002). No confirmed cases of DSP have been reported in BC, but since the symptoms are easily attributed to other ailments, it is unlikely to be diagnosed without specific testing.

The toxins described above can accumulate in filter-feeding shellfish and persist for long periods (>1 year for butter clams), often resulting in lengthy closures for harvesting. Outbreaks of PSP occur throughout the year and have a cyclical multi-year pattern possibly related to El Niño. Parasitic dinoflagellates can also infect crabs (bitter crab disease) and copepods.

Finfish are also at risk from other kinds of harmful algal blooms. For example *Heterosigma akashiwo* has been a problem for BC fish farmers and can also kill wild salmon (Schallie 2001; Wekell and Trainer 2002; Taylor and Harrison 2002). Non-toxic plankton blooms can also adversely affect finfish through oxygen depletion by decaying blooms and gill damage/congestion from plankton with sharp spines. The blooms may also attract other undesirable species such as jellyfish and *Noctiluca* (zooplankton dinoflagellate).

A synopsis of harmful algal blooms (HABs) in Canada's Pacific waters was produced by Taylor and Harrison (2002). This report includes data from the Canadian Food Inspection Agency shellfish testing program which reveal that all parts of the BC coast are susceptible to these harmful plankton. The report concludes with a number of questions relating to the causes and timing of harmful algal blooms. In particular, there is evidence of an overall increase in frequency of HABs, which could be tied to climate change, and a multi-year cycle in PSP levels which may be connected to ENSO (El Niño Southern Oscillation) fluctuations.

7.0 INTER-ANNUAL AND DECADAL FLUCTUATIONS

Zooplankton off Vancouver Island respond strongly to ocean-atmosphere climate forcing at time scales ranging from individual years (*e.g.*, El Niño events) to decadal "regime shift" fluctuations, and probably also to persistent trends resulting from global warming. The longest time series are from the oceanic Alaska Gyre (Ocean Station P, and Line P) and from the continental margin off southern Vancouver Island.

During the 1990s the trend off Vancouver Island and throughout much of the northeast Pacific was towards warmer water. The response off Vancouver Island and the northwest US included a shift to a less productive and more southerly mesozooplankton fauna (Mackas *et al.* 2001; Mackas and Galbraith 2002b). This trend reversed for a few years following the 1999 La Niña event, but appears to have resumed since 2003 (DFO 2006). Zooplankton anomalies in the Cape Scott region have been correlated with anomalies off southern Vancouver Island but to date have had smaller amplitude (Mackas *et al.* 2004).

There have also been climate related shifts in the seasonal timing of some of the zooplankton, including the dominant subarctic oceanic copepod *Neocalanus plumchrus* (Mackas *et al.* 1998). The shifts in zooplankton timing and community composition are correlated with declines in the reproductive success of planktivorous seabirds (Bertram *et al.* 2001) and recruitment/survival of fish such as sablefish and salmon (Batchedler *et al.* 2002; Mackas *et al.* 2006; DFO 2006). Offshore areas of the northeast Pacific have become less saline as well as warmer over the last 60 years. The winter mixed layer depth offshore is reducing, and it has been postulated that this could limit plankton productivity (Stocker *et al. eds*. 2001). Reasons for salmon variability in Alaska are being sought in zooplankton fluctuations related to changes in freshwater discharge (Royer *et al.* 2001). See Appendix I: Salmon for additional details on the relationship between salmon success, climate, and plankton.

8.0 PLANKTON IN INLETS AND FJORDS

Inlets and fjords differ from open water parts of PNCIMA in several important ways:

- degree of enclosure by land,
- average depth (many of the inlets exceed 200 m),
- input per unit area of fresh water and sediment, and resulting differences in water column profiles of salinity, turbidity, and density stratification,
- winter-summer temperature range.

Quantitative sampling and species identification of plankton in the fjords and inlets of the north and central BC coast has been intermittent in both temporal and spatial coverage. Unlike open-water locations in PNCIMA, archived remote sensing images do not offer a useful background data set for estimates of phytoplankton biomass, because the spatial resolution of most satellite data is too coarse for narrow fjords and inlets, and the color bias caused by turbidity and colored dissolved substances is often relatively large. Higher resolution (both spatial and spectral) satellite data are beginning to become available, but are not routinely archived unless there is a specific demand.

The knowledge base for both phytoplankton and zooplankton therefore comes from relatively infrequent research cruises targeting one or several inlets. Published data sets include: Le Brasseur (1955) and Gardner (1980) [coastwide surveys]; Parker *et al.* (1971) and Parker and LeBrasseur (1974) [Burke Channel and the Bella Coola estuary]; Stone (1977) [Knight Inlet]; Higgins and Schouwenberg (1973) and Hoos (1975) [Skeena River Estuary]; MacDonald *et al.* (1980) [Kitimat Arm]; and Mackas and Anderson (1986) [Alice Arm]. Copepods, euphausiids, ctenophores, and barnacle larvae are all frequently very abundant. Data from a 1977 coast-wide survey were used to classify zooplankton community composition according to water mass characteristics (Gardner 1982). Inlet sampling done as part of a 1979-80 ship-of-opportunity program found copepods to be the most common zooplankton, with barnacle larvae dominating the non-copepod population (Perry *et al.* 1981). The same study reported that diatoms dominated the larger sized phytoplankton, and flagellates the smaller. More recently, most "red tides" have been found to contain the non-toxic dinoflagellate *Noctiluca*, and fish losses have been reported from the diatom *Chaetoceros* (Ricker and McDonald 1995).

Based on 21 locations in southeastern Alaskan inland coastal waters, from April to November 1972, the highest plankton biomass occurred in May-June, dropping sharply in July and continuing to decline into November. Copepods and phytoplankton dominate the biomass, accompanied by chaetognaths, euphausiids, amphipods and barnacle nauplii (Mattson and Wing 1978). In a study of the waters around Prince of Wales Island, just north of Dixon Entrance, the phytoplankton bloom usually began in late April, and continued through May. A second bloom developed in July. Diatoms dominated the phytoplankton, while copepods were the most numerous zooplankton, followed by euphausiids, amphipods, chaetognaths, and larvae of barnacles, shrimps, crabs, molluscs, polychaetes and fish (Alaska Department of Fish and Game 1979a; 1979b). Plankton levels declined in the fall.

Phytoplankton productivity within the inlets and fjords of the central BC coast generally peaks in the spring, reducing during the summer, fall and winter. In Fitz Hugh Sound during 1978-80 the productivity was highest during June-July (Perry *et al.* 1981). However a recent study of an Alaskan fjord estuary (Glacier Bay) found unexpectedly high productivity throughout the spring, summer, and fall, possibly due to extensive mixing (Hooge and Hooge 2002).

The stratified surface waters of many of the inlets and fjords, particularly frontal zones, provide a favourable environment for plankton to bloom in the spring/summer, even though increased turbidity from glacial-fed runoff may reduce the depth of the euphotic zone. The sill regions often host higher densities of marine life (see Simard and Lavoie 1999). It appears that sill dynamics during tidal flow causes the aggregation of larger plankton (especially euphausiids) on the (tidal) upstream side of the sill. These aggregations were seen to be exploited by predators (Mackas *et al.* 2003).

Dense phytoplankton blooms, such as occur in Rivers Inlet and Laredo, Finlayson and Mathieson channels, can cause problems for finfish. The initial surge in dissolved oxygen levels can be followed by very low oxygen levels as bacteria breakdown the waste. Toxic blooms in the inlets and fjords are also of concern for existing and future aquaculture operations (Whyte *eds*. 2001). *Heterosigma akashiwo* can kill wild salmon, as well as those in ocean pens. In 1998 a program was initiated for the northern/central BC coast to monitor harmful algae (Purkis 2001). The following year a similar monitoring program was initiated by the Pacific Biological Station (PBS) to assist salmon farming operations around Vancouver Island, including Queen Charlotte Strait and the Broughton Archipelago, as well as Quatsino Sound (Haigh and Whyte 2001). First Nations people run their own monitoring programs in cooperation with the Canadian Food Inspection Agency (Wekell and Trainer 2002).

9.0 OPPORTUNISTIC PLANKTON MONITORING

Knowledge of offshore plankton is currently being enhanced by a program that takes advantage of 'ships of opportunity'. A device called a Continuous Plankton Recorder (CPR) can be deployed from merchant ships such as cargo vessels and oil tankers. This opportunistic sampling was developed by the Sir Alister Hardy Foundation for Ocean Science (SAFOS) and has been done in the Atlantic Ocean for the last 70 years (Batten and Welch 2002). After a test run in 1997, SAFOS initiated sampling of the North Pacific in 2000 from California to Prince William Sound, Alaska five times per year between March and September. In 2004 this route changed to run from the Puget Sound to Cook Inlet, Alaska and is run six times per year (Figure D.10). There is also an east to west Great Circle route that runs from Vancouver to Japan. It ran once per year in 2000 and 2001, but has been run three times per year from 2002 to the present.

The CPR device is towed behind the vessel and takes in a steady stream of water (and plankton) via a 1.27 cm^2 hole at the front end of the CPR. This is filtered between two sheets of silk mesh which are slowly sandwiched together, wound onto a roller, and stored in a preservative solution. A cassette, much like a film cartridge, holds the preserved silk sandwich and is replaced with a fresh cassette about every 800 km by ships crew. Using the ships log to indicate speed and location, sections of the mesh can be correlated to sections of the route (usually 10 km stretches). In this way large areas of the ocean can be regularly sampled at a very low sampling cost. Many of these samples are archived and a selection is processed for plankton species identification as funding allows. Currently this project is funded by the North Pacific Research Board and the Exxon Valdez Oil Spill Trustee Council. Recently, the transect from Vancouver to Japan has been coupled with an on-board bird observer in the hopes of finding correlations between plankton and bird species and abundance (Sydeman and Hyrenbach 2000) (also see Appendix K: Seabirds). Data from the North Pacific CPR surveys are freely available from SAFOS and some results have already undergone initial analysis (Batten and Welch 2002; Batten *et al.* 2003; PICES 2005).

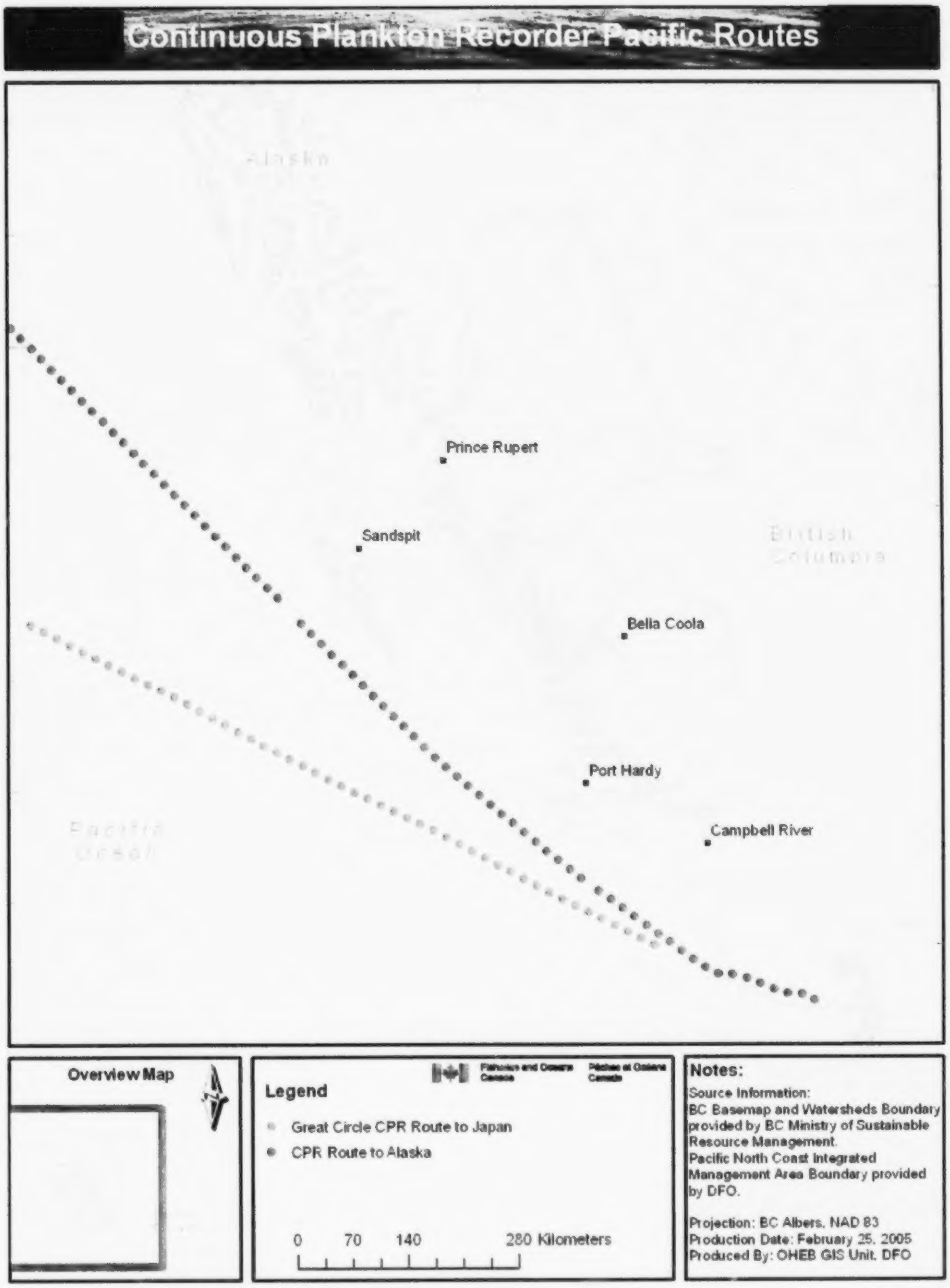
Continuous Plankton Recorder Pacific Routes
Alaska
Prince Rupert
Sandspit
British Columbia
Bella Coola
Port Hardy
Campbell River
Pacific Ocean
Overview Map
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
Great Circle CPR Route to Japan
CPR Route to Alaska
0
70
140
280 Kilometers
Notes:
Source Information:
BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
Pacific North Coast Integrated Management Area Boundary provided by DFO.
Projection: BC Albers, NAD 83
Production Date: February 25, 2005
Produced By: OHEB GIS Unit, DFO

Figure D.10 The current Continuous Plankton Recorder routes proximal to Canadian Pacific waters (data from Sonia Batten, Sir Alister Hardy Foundation for Ocean Science).

10.0 GLOSSARY

Advective – Related to transport by ocean currents.

Autotroph – An organism that supplies their own food, in this case by photosynthesis.

Behavioural convergence – Spatial aggregation for which the causal mechanism is at least in part the behavior of the organism.

Bioaccumulate – The net accumulation of a contaminant in an organism from all sources, including air, water and food. Toxic chemicals tend to bioaccumulate in the fatty tissues.

Calcite – Mineral composed of calcium carbonate.

Chlorophyll - A group of green pigments found in green plants, algae, and some bacteria necessary for energy production.

Centric - Radial symmetry.

Chemosynthetic autotroph – Organisms which supply their own food, through the use chemicals (like hydrogen sulfide) to provide the energy (food).

Ciliates – A class of protozoans distinguished by short hairs on all or part of their bodies.

Detrital - Dead or decaying organic matter.

Euphotic zone - The depth layer within which light intensity exceeds 1% of surface irradiance; in coastal regions this is usually 30 m or shallower.

Fluorescence –The physical process at which phytoplankton pigments absorb light and emit energy as visible light cause them to illuminate or appear to glow.

Heterotrophic - Derive nourishment from the consumption of other organisms.

Holoplankton - Organisms that are planktonic (drifting small organisms that inhabit the water column of the ocean) for their entire life cycle.

Lysis - Rupture and destruction of a cell.

N, P, Si, Fe – Inorganic nutrients nitrogen, phosphorus, silicon, and iron, respectively.

Olioclastic bacteria – Bacteria able to break down oil

Phylogenetic - The evolutionary history of a particular group of organisms.

Saxitoxin – Non-protein toxins produced by single celled marine organisms which maybe accumulated by shellfish and result in Paralytic Shellfish Poisoning (PSP).

Unicellular – A single celled organism.

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2007

ECOSYSTEM OVERVIEW:
PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX E: MARINE PLANTS

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1.0 INTRODUCTION

This chapter deals with large marine plants, specifically the benthically attached algaes (seaweeds) and sea grasses. Our knowledge of marine plants on the British Columbia (BC) coast is dominated by two species of kelp (*Nereocystis luetkeana* and *Macrocystis integrifolia*) and eelgrass (esp. *Zostera marina*). This is partially because these species are so common, but more importantly, these species form essential habitat for a huge number of other organisms including birds, invertebrates, and both juvenile and adult fish as well as providing much of the substrate for herring spawn. As habitat, these species form a critical component of ecosystem function in the nearshore. Kelp surveys have been done for a number of areas along BC's coast, but are rarely repeated, so temporal change is not well understood. There is evidence that *Macrocystis* increases in abundance relative to *Nereocystis* when sea surface temperatures increase, as they have been over the last 30 to 50 years. The effect of this global-warming-related change on the ecosystem is not known. Eelgrass beds are extremely sensitive to environmental change. So much so that in many cases of eelgrass decline, it is not possible to determine which environmental change was the ultimate cause. In terms of biodiversity, there are hundreds of known species of marine plants in the Pacific North Coast Integrated Management Area (PNCIMA, Figure E.0) (Johannessen *et al.* 2005; Sloan and Bartier 2000). Current data is insufficient to determine if this biodiversity is changing with time.

1.1 Marine Plants Defined

Benthic marine plants comprise four major groups: brown, green, and red algae, and seed plants. As the algal names suggest, these groups are recognized by their accessory photosynthetic pigments, which usually give them their distinctive color, and by other biochemical features and distinctive morphologies (Graham and Wilcox 2000). The brown, green and red benthic marine plants are known collectively as seaweeds, and they grow attached to rock or other organisms in the intertidal or shallow subtidal coastal environment. The seed plants include the seagrasses, which are adapted to marine life, and some salt-tolerant high intertidal plants, which are not discussed here. Diatoms, chrysophytes, tribophytes, and blue-green algae (Cyanophyta, or Cyanobacteria) also occur benthically in marine habitats, but they are not as conspicuous as the other groups and are not dealt with in this appendix.

Seaweeds, as their name implies, are adapted to living in the marine environment. Because of their simple morphologies (often one or a few cells thick, and all but a few species of kelp without conducting tissue), they obtain their inorganic nutrients for photosynthesis and other metabolic activities directly from seawater. Thus, most of their productivity occurs when plants are submerged. Species vary in their need for and ability to take up different inorganic nutrients. Seaweed ecology and physiology are treated in detail in Lobban & Harrison (1994).

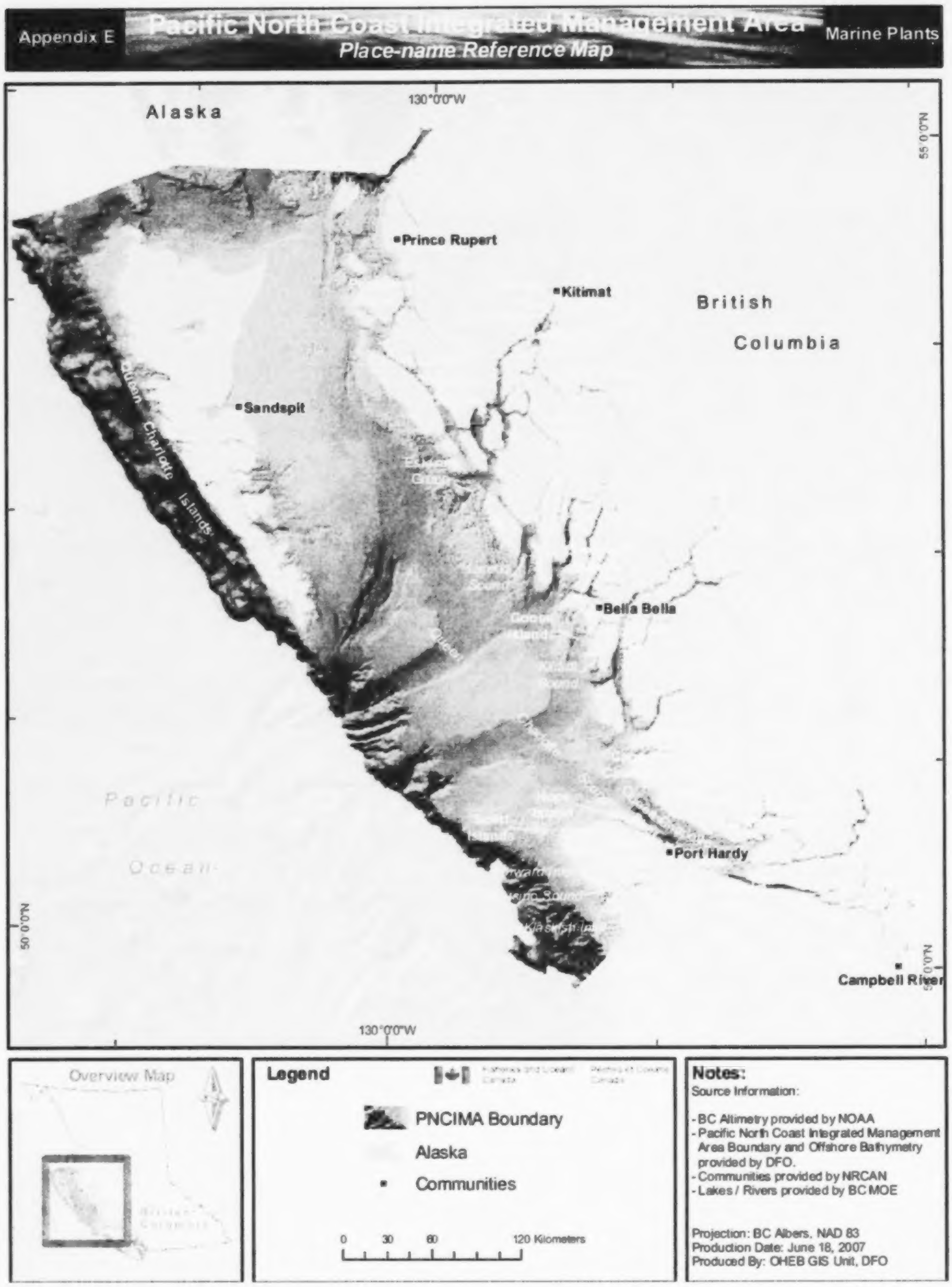
Appendix E
Pacific North Coast Integrated Management Area
Place-name Reference Map
Marine Plants
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Prince Rupert
Kitimat
British Columbia
Sandspit
Queen Charlotte Islands
Bella Bella
Pacific Ocean
Port Hardy
Campbell River
Overview Map
Legend
PNCIMA Boundary
Alaska
Communities
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
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Figure E.0 PNCIMA region showing locations and features of BC waters.

Seaweeds also vary in their tolerance to temperature, salinity, light intensity, desiccation, and water motion, which results in individualized horizontal (geographic) and vertical (shorezone) distributions. Species diversity usually increases from high to low in the intertidal zone and then decreases again as water depth increases. Because they need light for photosynthesis, seaweeds occur from the splash zone to depths of rarely more than 30 m near the coast. However, in offshore areas such as Bowie Seamount, species can be found at depths of at least 35 m (Scagel 1970). These depths are still relatively shallow compared to the record depth of 268 m on a tropical seamount (Lobban and Harrison 1994).

Seaweeds also vary in their morphologies and chemical compositions, making them differentially attractive (or in a few cases, repellent) to herbivores. Sea urchins are a major grazer of seaweeds in temperate waters (Foreman 1977; Coon 1983), but mesograzers such as chitons and limpets can also have significant effects (Lobban and Harrison 1994). Effects of grazers can vary dramatically between regions even when community composition is very similar (Dethier and Duggins 1988).

Seaweeds reproduce by spores or gametes, and most species have an alternation of either isomorphic or heteromorphic generations (Lobban and Harrison 1994; Graham and Wilcox 2000).

BC has a particularly diverse assemblage of seaweeds (Scagel *et al.* 1993). Scagel (1957) summarized the state of knowledge on marine algae and included keys to genera, followed by a floristic treatment of the benthic marine green algae (Scagel 1966). No comprehensive flora of the benthic marine plants of BC has been published. Lüning (1990) described the most important features of zonation of intertidal and subtidal vegetation common to the coast from BC to central California.

1.2 Marine Plant Species List

The herbarium of the University of British Columbia (UBC) houses over 5700 specimens (402 different taxa) collected by Scagel and his associates in the central coast region of BC over the past 50 years. The number of species is similar to the 376 whose distributions overlap the region according to Scagel *et al.* (1993). However, comparison of these two lists reveals that 66 taxa that should occur within the region, based on records north and south of the central coast, have not yet been collected there. Many of these are microscopic and have probably been overlooked in samples collected thus far. However, some species are conspicuous and should have been observed. Herbarium specimens could have been misidentified, species could have been overlooked or seasonally absent during sampling, or taxonomy may have changed as a result of molecular techniques. A combination of the two lists provides a list of 419 taxa, which, together with Sloan and Bartier's (2000) list of marine plants from the Queen Charlotte Islands, form an approximate listing of the plant diversity for the PNCIMA region (for a comprehensive list see the Biophysical Overview report (Johannessen *et al.* 2005).

Despite falling entirely within van den Hoek's (1984) northeast Pacific cold temperate zone and Valentine's (1966) Oregonian Province, the PNCIMA region shows characteristics of a transitional zone. It is here that the northern limits of some species are reached (Table E.0)(Norris and Abbot 1972; Scagel *et al.* 1993; Lindstrom and Gabrielson 1989; Wynne *et al.* 1973; Phillips 1979). The UBC database reveals northern records for other species that could be easily misidentified, so specimens should be verified before these northern records can be confirmed. For other species, the central coast represents their southern limits (Hawkes *et al.* 1978; Scagel *et al.* 1993; Wynne 1985).

Table E.0 Marine plant species at their range limits in PNCIMA (source: Norris and Abbot 1972; Scagel *et al.* 1993; Lindstrom and Gabrielson 1989; Wynne *et al.* 1973; Phillips 1979; UBC database; Hawkes *et al.* 1978; Wynne 1985).

Species at their northern limit	**UBC northern records**
Cumagloia andersonii	*Fauchea fryeana*
Dictyoneuropsis reticulata	*Gelidium coulteri*
Gloiosiphonia verticillata	*Grateloupia doryphora*
Hollenbergia nigricans	*Halymenia gardneri*
Laminaria sinclairii	*Halymenia schizymenioides*
Phyllospadix torreyi	*Hersposiphonia grandis*
Pleonosporium squarrulosum	*Holmesia californica*
Polyneuropsis stolonifera	*Hymenena setchellii*
Postelsia palmaeformis	*Isabbottia ovalifolia*
Pterothamnion reversum	*Membranoptera multiramosa*
	Myriogramme puichra
	Prionitis cornea
Species at their southern limit	
Codium ritteri	
Eudesme virescens	
Hommersandia maximicarpa	
Laminaria yezoensis	
Tayloriella divaricata	

2.0 KELP

Kelp is the common name for seaweeds belonging to the brown algal order Laminariales. They include the largest known marine algae, the floating kelp *Nereocystis* (bull kelp) and *Macrocystis* (giant kelp), which are reported to reach 30 m or more in length. The Northeast Pacific in general and the BC coast in particular are rich in both species number and species abundances: 27 species of kelp are reported for this region. Druehl (1970) plotted the geographic distribution of kelp species along the northeast Pacific coast.

A few species occur in the mid intertidal (*Alaria* spp., *Hedophylum sessile*, *Postelsia palmaeformis*), but most are restricted to the low intertidal or subtidal. The floating kelp species occurring in this area, *Nereocystis luetkeana* and *Macrocystis integrifolia*, can form large offshore or narrow, fringing beds along coastal BC. *Macrocystis pyrifera* is common in Sitka Sound, Alaska, and from central California to Baja California (O'Clair and Lindstrom 2000) . Its apparent absence in the intervening area is puzzling. The possibility of *M. pyrifera* occurring in central BC should be considered.

Temperate kelp beds are among the most productive ecosystems in the world (Mann 1982). In general, kelp productivity ranges from 400-1900 g C m^{-2} yr^{-1} (Westlake 1963). In St. Margaret's Bay, Nova Scotia, macrophyte beds were found to contribute about 75% of the total primary production (Mann 1982). Kelp beds are important spawning and nursery areas for fish and invertebrates, and kelp contribute a significant amount of fixed carbon to the nearshore ecosystem (Duggins *et al.* 1989). Herring, salmon, surf smelt, sand lance, abalone, and sea urchins are among the important species to utilize kelp beds (Shaffer 2004).

Leaman (1976; 1980) compared his summer 1975 survey of kelp fishes in relatively small Barkley Sound *Nereocystis* beds with a two-day investigation of a 15 ha mixed kelp bed of *Macrocystis* and *Nereocystis* and a smaller *Nereocystis* bed off Deer Island in Beaver Harbour, near Port Hardy. He observed an absence of neritic fishes in the Deer Island beds in contrast to their abundance in Barkley Sound; benthic fishes were of similar diversity among all beds, although species composition varied. Leaman noted differences in the relative depth distributions and densities of the floating kelps between Barkley Sound and Beaver Harbour, and differences in understory species.

The BC Research Council inventoried *Nereocystis* and *Macrocystis* beds along the BC coast during the summer of 1946 (BCRC 1947a; 1947b). They estimated a harvestable biomass of 50,815 and 8,570 tons, respectively, for the central zone, extending from Cape Scott and Seymour Narrows on Vancouver Island to Cape Caution, and 15,370 tons and 5,660 tons, respectively, for beds in their Northern Zone but in areas that fall within the central coast region of this report.

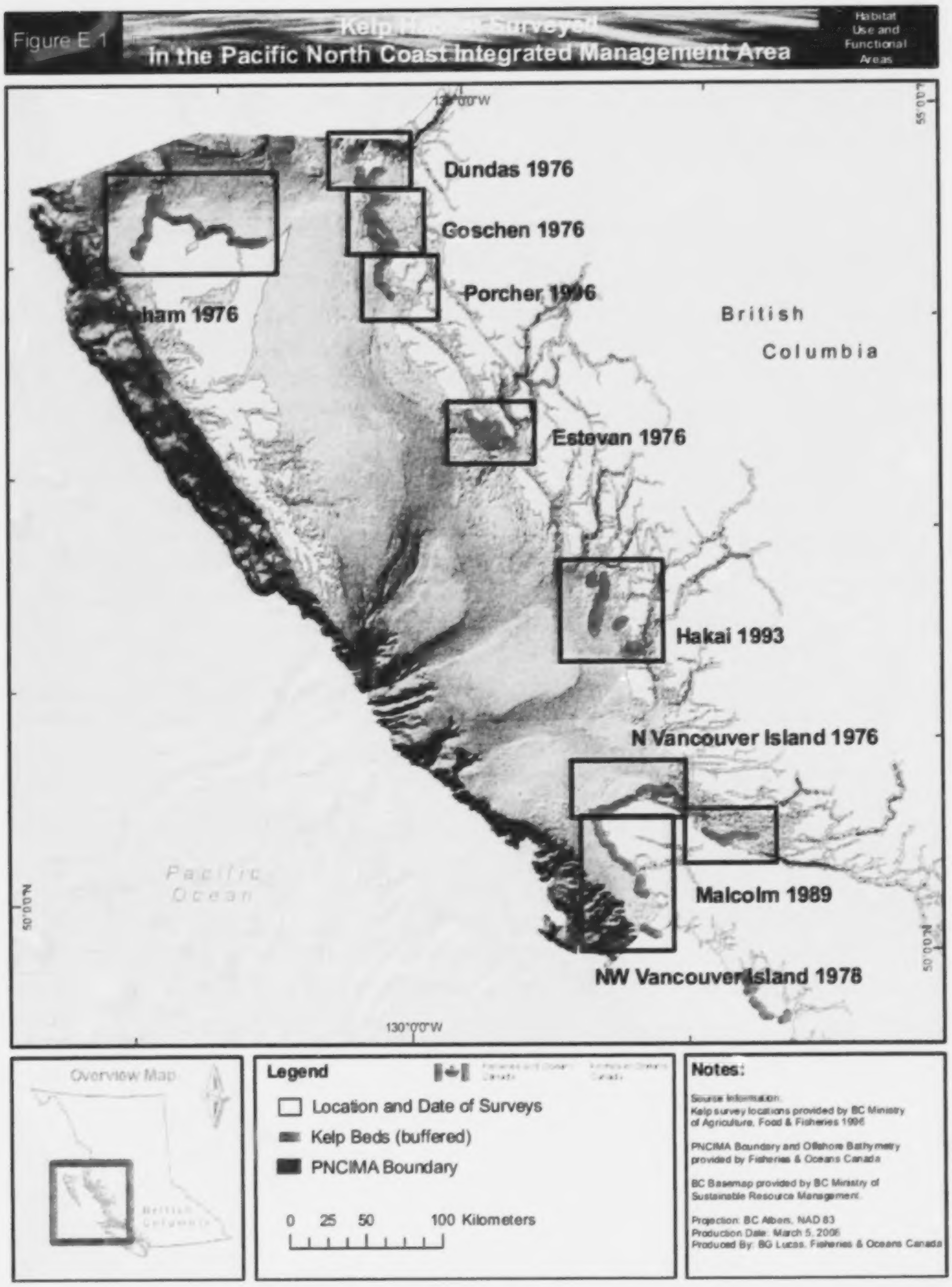
Figure E.1
Kelp Habitat Surveyed
In the Pacific North Coast Integrated Management Area
Habitat Use and Functional Areas
130°0'0"W
55°0'0"N
Dundas 1976
Goschen 1976
Porcher 1996
ham 1976
British Columbia
Estevan 1976
Hakai 1993
N Vancouver Island 1976
Malcolm 1989
NW Vancouver Island 1978
Pacific Ocean
50°0'0"N
Overview Map
Legend
Location and Date of Surveys
Kelp Beds (buffered)
PNCIMA Boundary
0 25 50 100 Kilometers
Notes:
Source Information:
Kelp survey locations provided by BC Ministry of Agriculture, Food & Fisheries 1996
PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada
BC Basemap provided by BC Ministry of Sustainable Resource Management
Projection: BC Albers, NAD 83
Production Date: March 5, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Figure E.1 Locations of surveyed kelp beds in PNCIMA, buffered to enhance visibility (data from BC Ministry of Agriculture, Fisheries and Food 1996).

More recently, floating kelp have been the subject of a number of inventories of standing stocks using the Kelp Inventory Method (KIM-1) developed by Foreman (1975) or a modification thereof (summarized by Sutherland 1990; Field 1996). Inventory areas are shown in Figure E.1, and results are summarized in Table E.1. Basically, KIM-1 combines bed area, density and species composition from infrared aerial photography with field-determined bed density and mean plant weight to provide species-specific biomass estimates for each km-wide section of coastline. The majority of PNCIMA coastline has not been surveyed, therefore the absence of kelp beds on the figure does not indicate the absence of kelp. The kelp beds of the PNCIMA region represent about 80% of the total surveyed biomass for the coast of BC.

Table E.1 Estimated annual yield of BC kelp (*Nereocystis* and *Macrocystis*) biomass in surveyed areas. Locations in bold are within PNCIMA (data provided by the BC Ministry of Agriculture, Fisheries and Food).

Inventory Area	Most Recent Year of Survey	Coastline Length (km)	Bed Area (ha)	Total Standing Crop (wet tonnes)	Annual Yield (wet tonnes)	Annual Yield Excluding Protected Areas
Port Hardy-Malcolm Island	1989	40	761	37 934	7 587	7 587
North Vancouver Island	1976	68	885	38 077	7 604	6 287
Northwest Vancouver Island	1978	72	840	48 615	9 723	5 918
Nootka Sound	1995	85	850	73 836	14 767	8 611
Strait of Juan de Fuca	1988	118	511	50 148	10 030	6 732
Estevan Group	1976	82	1 470	77 615	15 524	8 298
Dundas Group	1976	61	1 527	74 350	14 870	4 854
Melville Group	1981	16	127	2 997	599	0
Porcher Group	1996	122	1 741	113 575	22 715	3 056
Shakes	1981	14	0	1 968	394	394
North Graham Island	1976	162	2 375	77 410	15 482	9 303
Hakai Pass/Bardswell Group	1993	126	1 550	55 224	11 045	2 602
TOTAL		966	12 707	651 749	130 340	63 642

Modified from Lindstrom (1998).

Most beds have been surveyed only once during the 20-year period 1974-93. The exception is the Malcolm Island area in Queen Charlotte Strait, which was assessed in 1974, 1978, 1980, 1983 and 1989. Comparisons among the years reveal that the total bed area grew slightly during this period, and *Macrocystis* abundance increased whereas *Nereocystis* area declined (Sutherland 1990). Foreman (1984) had earlier noted this change in the Malcolm Island bed, namely that the high *Nereocystis* densities from 1974 to 1978 were unusual and appeared to be correlated with record low mean annual seawater temperatures and salinities during that period. A comparison of beds in the Estevan Group area between surveys in 1946 and 1976 (using different methods) revealed significant differences in the size of beds between the two periods (some increasing, others disappearing; (Field *et al.* 1977)). A comparison of beds at the north end of Vancouver Island between 1967 and 1976 (again, using different methods) revealed a large increase in *Nereocystis* area and biomass and a similar significant decrease in *Macrocystis* area and biomass (Coon *et al.* 1981), whereas beds of the northwest coast of Vancouver Island were comparable between 1967 and 1978 (Coon *et al.* 1982). These shifts in species composition, with increases in relative abundance of *Nereocystis* from 1967 to 1978 and of *Macrocystis* from 1974 to 1993, coincide with a documented regime shift in the North Pacific (Mantua *et al.* 1997; Anderson and Piatt 1999).

As previously noted, urchins are a major grazer of kelp, particularly *Nereocystis*. An abundance of urchins can decimate kelp beds, creating barren ground. Such a devastation has been documented by Foreman (1977) in the Strait of Georgia and by Coon (1983) at Porcher Island, where biomass declined from 36,000 to 195 wet tonnes between September 1976 and September 1981 due to urchin grazing. Sea otters, a major predator of urchins, are often associated with healthy kelp beds (Estes 1996).

Coon & Roland (1980) examined harvesting impacts on *Macrocystis integrifolia*, and Coon (1983; 1990) reviewed provincial management strategies and inventory methods. Mumford (1987; 1992) published a bibliography on *Nereocystis luetkeana*. Kelp beds in the vicinity of salmon farms in the Broughton Archipelago, Johnstone Strait, and northwest Vancouver Island have been mapped by the Living Oceans Society (LOS 2003).

Druehl, his students and associates have published extensively on BC kelp (see Scagel *et al.* 1993 for references). Druehl and Kemp (1982) studied changes in blade morphology and growth characteristics of *Macrocystis integrifolia*, which included specimens from Malcolm Island. Foreman (1976; 1984) reported on the ecology and population dynamics of *Nereocystis luetkeana*, including specimens from Malcolm Island.

3.0 SEAGRASSES

Seagrasses are flowering plants that live in the marine environment. *Zostera marina*, commonly called eelgrass, forms extensive meadows in soft sediments, such as sand and mud, in the lower intertidal and shallow subtidal. Eelgrass beds are most common in protected waters, such as heads of inlets, but they also occur in soft sediments along other shores. The beds provide essential habitat for waterfowl, crab, herring and juvenile salmon (BC MSRM 2002). They also stabilize sediments and contribute to nutrient cycling in both direct and indirect ways (Phillips and Menez 1988; Dunster 2003). The importance of eelgrass beds to the life cycles of economically important fish and shellfish has led Washington State to adopt a "no net loss" policy for eelgrass. In BC, Environment Canada and The Bullitt Foundation funded a discussion paper, Eelgrass Conservation for the BC Coast (Wright 2002), which concentrated on eelgrass beds in the Strait of Georgia, threats to their survival, the importance of mapping and monitoring, and difficulties with restoration and protection.

Although a single species of *Zostera*, *Z. marina*, is native to the Pacific coast of North America, Backman (1991) recognized five ecotypes, based on differences that were maintained in common garden experiments. Three of the ecotypes occur in Washington State, *Z. marina* var. *phillipsii* and *Z. marina* var. *marina* (as var. *typica*) in Puget Sound and *Z. marina* var. *latifolia* on the outer coast. *Zostera marina* var. *marina* occurs primarily in the intertidal whereas var. *phillipsii* and var. *latifolia* are primarily subtidal. The leaves of var. *latifolia* are significantly wider than those of other varieties. Backman did not examine any specimens from BC.

The introduced species, *Zostera japonica*, found in the Strait of Georgia at a higher elevation than *Z. marina*, has not yet been reported in PNCIMA.

Before 2000, most eelgrass mapping in BC was carried out by governmental agencies as part of regional resource planning, management, or resource-based activities (see Sec. 5.2 Vegetation of Herring Spawning Grounds). Since 2000, interest in the health of eelgrass beds has intensified, and the BC Seagrass Conservation Working Group network, an NGO, is spearheading fine-scale eelgrass mapping, monitoring and conservation for all of coastal BC. An eelgrass bed mapping atlas is available online (CMN 2006). Additional maps that may be of interest to eelgrass mappers are cited in Dunster (2003). Dunster also lists the Living Oceans Society as the contact agency for coarse-scale eelgrass mapping in the North Coast Fjords ecosection.

In 2002, the Northwest Stewardship Society undertook an initial survey of potential eelgrass sites in Douglas Channel from Bish Creek north to the Kitimat River estuary, using an underwater camera. Also in 2002, the Heiltsuk Fisheries Program Eelgrass Project began a reconnaissance of an eelgrass lagoon that is currently being mined for marine clay (Dunster 2003). Both groups are working with the SeaChange Marine Conservation Society. Coastal & Ocean Resources Inc. has mapped eelgrass beds in the

Douglas Canal area near Kitimat, including Kitimat Arm, Kitkiata Inlet, Hawkesbury Island, Goat Harbour, and Gardner Channel (two sites) using their towed underwater Seabed Imaging and Mapping System (SIMS); data are owned by the University of Victoria (Dunster 2003). Living Oceans Society's maps of eelgrass beds in the vicinity of salmon farms in the Broughton Archipelago (southeastern Queen Charlotte Strait), Johnstone Strait, and northwest Vancouver Island (including Quatsino Sound) are available online (LOS 2003).

Three species of surfgrasses are recorded for the BC's central mainland coast: *Phyllospadix scouleri*, *P. serrulatus*, and *P. torreyi* (Pojar and MacKinnon *eds*. 1994; Gabrielson *et al.* 2000). In contrast to eelgrass, surfgrass flourishes on low intertidal to shallow subtidal bedrock on exposed coasts. Phillips (1979) provided ecological information on the species of *Phyllospadix* occurring from Oregon to Vancouver Island, including elevation of occurrence and flowering phenology.

4.0 COMMERCIAL HARVESTING

The Ministry of Agriculture, Food and Fisheries is responsible for the management of commercial marine plant harvests in BC. A harvest licence is required, which stipulates the species, quota, method of harvest, and area of harvest. The royalty levied on harvested wet tonnage varies from $10 per tonne for kelp to $100 per tonne for *Porphyra*, *Enteromorpha* (now *Ulva*), *Rhodymenia* [sic—presumably *Palmaria*], and *Monostroma*. Most other algae are charged $50 per tonne. Data on province-wide harvests from 1992-2001 is shown in Figure E.2.

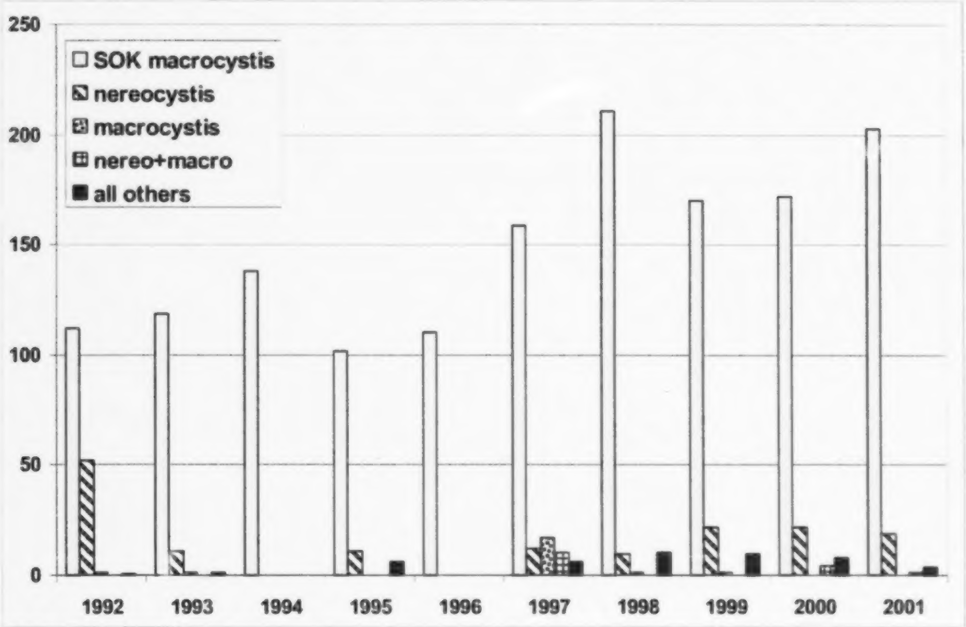

Figure E.2 Seaweed harvests in BC, 1992-2001. SOK = herring spawn on kelp (data from BC Ministry of Agriculture, Fisheries and Food).

5.0 MARINE PLANT COMMUNITIES

PNCIMA has a wide variety of marine plant flora. Many studies of marine plants in the area are dated or for a very limited geographical area, making it difficult to assess current status and long term variability for kelp and sea grasses. Older studies have also used different methods, making temporal analysis difficult. Studies monitoring seasonal variability are also lacking. A summary of studies conducted in the PNCIMA area illustrates the diversity and importance of plant communities in marine ecosystems.

5.1 General Studies

Scagel (1961) reported on the oceanography, notably temperature and salinity, meteorology, and geological formations and history in Queen Charlotte Strait in the 1950s and related the geographic distribution of seaweeds there to these factors. He provided a list of common benthic organisms along the Strait as well as data on their horizontal distribution, from Hope Island to the eastern end of the Strait, their vertical distribution at Hope Island, and a comparison of vertical distributions of some intertidal species at Hope Island, Deer Island, and Cluxewe (as Klucksiwi) River. The results reveal that more than half of these common species drop out between Hope Island and the innermost sites and that vertical distributions are somewhat to distinctly lower as one moves inside the strait, where salinity is lower.

Adkins (1977) reported on the state of knowledge of marine resources in the Queen Charlotte Sound region, drawing heavily on Scagel's 1961 species list for her one-page marine plant summary.

Petro-Canada (1983) reviewed studies of marine plants in the Queen Charlotte Islands and adjacent areas.

The North Island Straits Coastal Plan (BC MSRM 2002) discusses the importance of eelgrass and kelp beds in the area, the potential interest in kelp aquaculture off Malcolm Island, and in which of the 66 coastal units marine plant aquaculture is appropriate, conditionally acceptable, or inappropriate.

5.2 Vegetation of Herring Spawning Grounds

Three areas of the BC's central mainland were photographed aerially in 1979 (see Bennett 2003) with both Ektachrome and color infrared film in order to map shoreline vegetation in the Thompson Bay area (Haegele and Hamey 1980c), in Laredo Sound (Haegele and Hamey 1980b), and in Kildidt Sound (Haegele and Hamey 1980a). Vegetation to a maximum depth of 10 m was mapped at a scale of 1:6000, based on texture and color. Five categories of marine plants were recognized: seagrasses, rockweed, red algae, brown algae (including kelp and *Sargassum muticum*), and green algae. Published vegetation maps are at scale of 1:21,000 or 1:23,000. No ground-truthing was carried out at these locations, but at other sites there was a close correspondence between air photos and diver identifications.

A diving survey was carried out on the west coast Vancouver Island in Quatsino Sound, Forward Inlet and Klaskish Inlet (Haegele and Hamey 1987).

Bennett (2003) described Haegele's eelgrass data collection methods and the form and structure of his data to make them more readily available to other applications, including GIS mapping and analysis.

5.3 Shore-zone Bio-bands

The shoreline of BC has been mapped to identify its biophysical attributes, namely landform, substrate, slope, exposure, and major biota (BC MSRM 2005; Howes *et al.* 1997; 1999; Searing and Frith 1995). The shore biota is described as "bio-bands", assemblages of intertidal species visible from the air and named for dominant species or assemblages. Morris & Thuringer (2001) summarized bio-band definitions for the west coast of Vancouver Island and definitions of biophysical characteristics associated with various habitats.

Shore-zone data have been used by the Coast Information Team (CIT 2003) to identify 59 shoreline categories (17 representative types of coastal classes times 5 wave-energy classes less 4 man-made or unidentified categories) that are potential ecosystem targets for protection in central and northern coastal BC. Among the bio-band assemblages, CIT focused on saltmarsh vegetation, eelgrass beds and kelp beds as the major nearshore habitats because of their high biological productivity and sensitivity to human impacts and because "these categories are recognized ecologically, are protected by policy, and are the best surrogates at this scale to represent a range of habitats" (CIT 2003). They acknowledged, however, that these habitats are not necessarily the most diverse and therefore selected a Habitat 3 category (representing the highest diversity of intertidal biota) as an additional target. This habitat occurs on semi-exposed, lower intertidal bedrock. Indicator bio-bands are mussels-barnacles, chocolate brown algae, surfgrass, urchins, and *Nereocystis*; indicator species include diverse red algae, *Hedophyllum sessile, Egregia menziesii, Eisenia arborea, Laminaria setchellii,* and *Phyllospadix* spp. Application of a MARXAN analysis indicated that more than 30% of the linear saltmarsh, eelgrass, and kelp bed shoreline could be preserved by protecting less than 20% of the total shoreline (CIT 2003). Offshore analyses rated the following important algal areas high for conservation: Goose Islands, Bardswell Islands and vicinity, the Scott Islands, the entrance to Queen Charlotte Strait, and the Broughton Archipelago.

5.4 Intertidal Communities

A study by CERF (Coastal Ecosystems Research Foundation) (CERF 2004; Lamb *et al.* 1999), extending for about 30 km from Allison Harbour in Queen Charlotte Strait to Takush Harbour in Smith Sound, classified 32 intertidal sites into four habitat types based on intertidal sessile species. Exposed sandy beaches were mostly devoid of sessile algae and invertebrates. Exposed rocky shores, the most frequently surveyed habitat type (37.5%), were indicated by *Codium fragile*, *Corallina gracilis* [probably *Corallina vancouveriensis*], *Egregia menziesii*, *Hymenena setchellii*, *Microcladia borealis*, *Mazzaella splendens*, *Phyllospadix* spp., and *Porphyra* spp. Many of these exposed rocky sites had offshore *Nereocystis* and *Macrocystis* kelp beds, and one of the sites had the northernmost record of *Postelsia palmaeformis*. *Cladophora* sp. was the indicator species for sheltered mud beach habitat, and *Bryopsis* sp., *Neorhodomela* sp. (as *Rhodomela* sp.), *Petrocelis* sp. (the alternate phase of *Mastocarpus*), and some of the species diagnostic of exposed rocky shores characterized semi-exposed rocky habitats (moderately sheltered rock and sand, representing 34% of sites sampled). Other organisms, such as *Fucus*, *Balanus*, *Semibalanus*, *Ulva*, *Littorina* and limpets, occurred at all rocky site types and were thus not useful at sorting sites into categories; however, they were indicative of tidal zones. Thirteen of the 32 sites were revisited in 2002; results from this survey have yet to be analyzed.

5.5 Subtidal Communities

The CERF study recognized up to seven subtidal habitat types, each dominated by a different set of species (Lamb *et al.* 1999). Exposure and current were thought to determine the community present in each habitat type. The habitats identified were: (1) a protected bay, mostly in a *Nereocystis* kelp bed, *Membranipora* and *Tonicella lineata* dominant; (2) areas exposed to heavy wave action, often with sandy substrate, *Ulva* and *Zostera* dominant; (3) rocky bottom leading into sand or mud, encrusting coralline algae and *Luidia foliolata* dominant; (4) rocky substrate, *Strongylocentrotus* (and articulated coralline algae) dominant; (5) exposed sites, substrate not specified but presumably bedrock based on the dominant species, *Henricia leviuscula* and *Phyllospadix*; (6) "generally exposed coastal sites", encrusting coralline algae and *Acmea mitra* dominant; and (7) "rocky substrate", *Allopora porphyra* and *Coryphopterus nicholsi* dominant.

5.6 Estuaries

Estuaries are highly productive habitats where terrestrial, freshwater and marine ecosystems meet. Although they account for less than 3% of the BC shoreline, they are used by 80% of all coastal wildlife (PECP 2005). 442 large estuaries were identified in BC from existing mapping products (PECP 2004). MacKenzie *et al.* (2000) surveyed twenty eight central and north coast estuaries. Their objectives were to acquire site-specific information about estuarine ecosystems based on plant community types, to describe the range of estuary types, including biological and geomorphogical information, to create a site classification, and to identify estuaries with particularly high habitat value or rare ecosystems. The report also included a proposed ecosystem classification framework for estuarine wetlands, as part of a broader Wetland and Riparian classification (MacKenzie and Banner 1999). Fourteen estuarine ecosystem associations were recognized. A mapping system has been developed for BC estuaries by Howes *et al.* (1999), including definitions of algal and eelgrass-dominated bio-bands.

5.7 Genetic Diversity

In addition to the genetically-diverse assortment of species in PNCIMA, there is also intraspecific diversity, such as that reported for *Zostera marina* in Washington State (Backman 1991). Lindstrom *et al.* (1997) found distinct genotypes in the red alga *Palmaria mollis* from northwestern and northeastern areas of Vancouver Island. Specimens from northwestern Vancouver Island were more similar to other outer coast sites (outer Queen Charlotte Islands and Sitka, Alaska), whereas those from northeastern Vancouver Island were more closely related to inner coastal sites (Strait of Georgia and Ketchikan, Alaska). Ongoing research by Lindstrom (unpublished) has revealed distinctive genotypes for other intertidal algae in the northern Vancouver Island area.

6.0 SPECIES AT RISK

The BC Ministry of Sustainable Resource Management (BCMSRM) North Island Straits Coastal Plan (BC MSRM 2002) points out the occurrence of red- and blue-listed species of algae in the various shoreline units and warns against tenures and activities that would disturb these species (Table E.2). The draft Quatsino Sound Coastal Plan (BC MSRM and DFO 2004) also records red-listed and blue-listed species. Other red-listed species are reported to occur within the region. However, as previously mentioned, the identity of several of these species requires verification.

Table E.2 Provincial Red and Blue listed algal species occurring or reported to occur in PNCIMA (source: BC MRSM 2002; BC MSRM and DFO 2004).

Species	**Status**	**Location**	**Coastal Plan**
Tayloriella divaricata	Red	Broken Islands unit	North Island Straits
Leptonematella fasciculata	Red	Call Inlet unit	North Island Straits
Hollenbergia nigricans	Red	Deserters and Walker Group	North Island Straits
Dictyoneuropsis reticulata	Red	Hope Island area	North Island Straits
Laminaria sinclairii	Red	Hope Island area	North Island Straits
Myriogramme pulchra	Red	Hope Island area	North Island Straits
Desmarestia tortuosa	Red/Blue	Upper Holberg unit	Quatsino Sound
Laminaria sinclairii	Red	San Josef-Cape Parkins unit	Quatsino Sound
Percursaria dawsonii	Blue	San Josef-Cape Parkins and Quatsino Approaches-Brooks Bay units.	Quatsino Sound
Bonnemaisonia geniculata	Red	PNCIMA	Unknown
Codium ritteri	Red	PNCIMA	Unknown
Eugomontia sacculata	Red	PNCIMA	Unknown
Phycodrys riggii	Red	PNCIMA	Unknown
Stictyosiphon tortilis	Red	PNCIMA	Unknown
Tayloriella abyssalis	Red	PNCIMA	Unknown

7.0 INFORMATION GAPS

- It is not yet known which, if any, species could provide the best indicators of environmental health. Likewise, the long term impact of global warming has not been assessed.
- Productivity of kelp beds and eelgrass beds needs to be determined.
- A comprehensive list of marine plant species occurring in BC has not yet been developed.
- Species that have been found on either side of the region, but not within it, may be discovered with additional surveys.
- The identity of UBC herbarium specimens from the region should be re-examined and their taxonomy updated, if indicated.
- Long-term monitoring stations would help fill knowledge gaps for the region, and allow comparisons of community dynamics in PNCIMA to those of other areas of the northeast Pacific.
- Marine plant beds and estuaries in PNCIMA have not been fully mapped.

8.0 ACKNOWLEDGEMENTS

This chapter is a summary of a comprehensive reporting on marine plants in the central coast management area that was modified to include the north coast in the Biophysical Overview Report for PNCIMA (Johannessen *et al.* 2005). The authors would like to thank John Pringle for reviewing the initial report and Jake Schweigert for reviewing this version.

9.0 GLOSSARY

Heteromorphic generations – Appearing distinct or different.

Isomorphic – Appearing identical, in this case between generations.

Mesograzers – Use individual seaweeds as both habitat and food.

Morphology – Physical form.

Neritic – Fish residing in waters over the continental shelf that is less than 200 meters deep.

Phenology – The study of the seasonal timing of life cycle events (changes in plants and animals).

10.0 REFERENCE LIST

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2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX F: INVERTEBRATES

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1.0 INTRODUCTION

The purpose of this chapter is to inform the public, planners, as well as oceans, resource and habitat managers on the state of knowledge about marine invertebrates in the Pacific North Coast Integrated Management Area (PNCIMA, Figure F.0) as we presently understand it; the issues surrounding these organisms; and the information gaps with respect to marine invertebrates that need to be addressed to provide informed management decisions.

The number of known marine invertebrate species is estimated to exceed 140,000 (Ruppert and Barnes 1994), and well over 6,000 species are estimated to occur in the North-eastern Pacific Ocean in the vicinity of PNCIMA (Austin 1985). The distribution of marine invertebrates throughout PNCIMA ranges from the intertidal zone to the deep-water abyss and from sheltered coves to the exposed open coast.

Due to their wide and extensive distribution, marine invertebrate communities may be affected by a wide variety of human activities such as: fishing, aquaculture development and facilities, oil and gas exploration and extraction, shipping, coastal community development and expansion, coastal mining activities, and forestry related activities such as pulp and paper waste discharge and log storage.

The state of knowledge for most of these animals is minimal and very fragmented. Historically, the only information on non-harvested species of invertebrates in the PNCIMA area was from the traditional ecological knowledge of First Nations' communities and a very few taxonomic collection surveys of the area. Programs for the systematic and ongoing collection of data on non-harvested invertebrate species have just recently been initiated. More detailed and specific information is available on the commercially harvested species. It is not the intention of this chapter to detail the most up to date commercial fisheries information but instead to direct the reader to a link to the most recent source of this information, usually in the form of commercial fishing plans and science advisory reports.

There are fundamental knowledge gaps for marine invertebrates, starting from: What are the animals in the area (standard taxonomic information)? Where are the animals normally found? What is their basic biology? What is their role in the ecosystem? And what are the impacts of various anthropogenic activities on these animals?

Not all the groups of animals will be addressed in this chapter, but we will try to touch on groups of animals that we know are being impacted and try to put this in context of what this will mean when trying to manage at the ecosystem level.

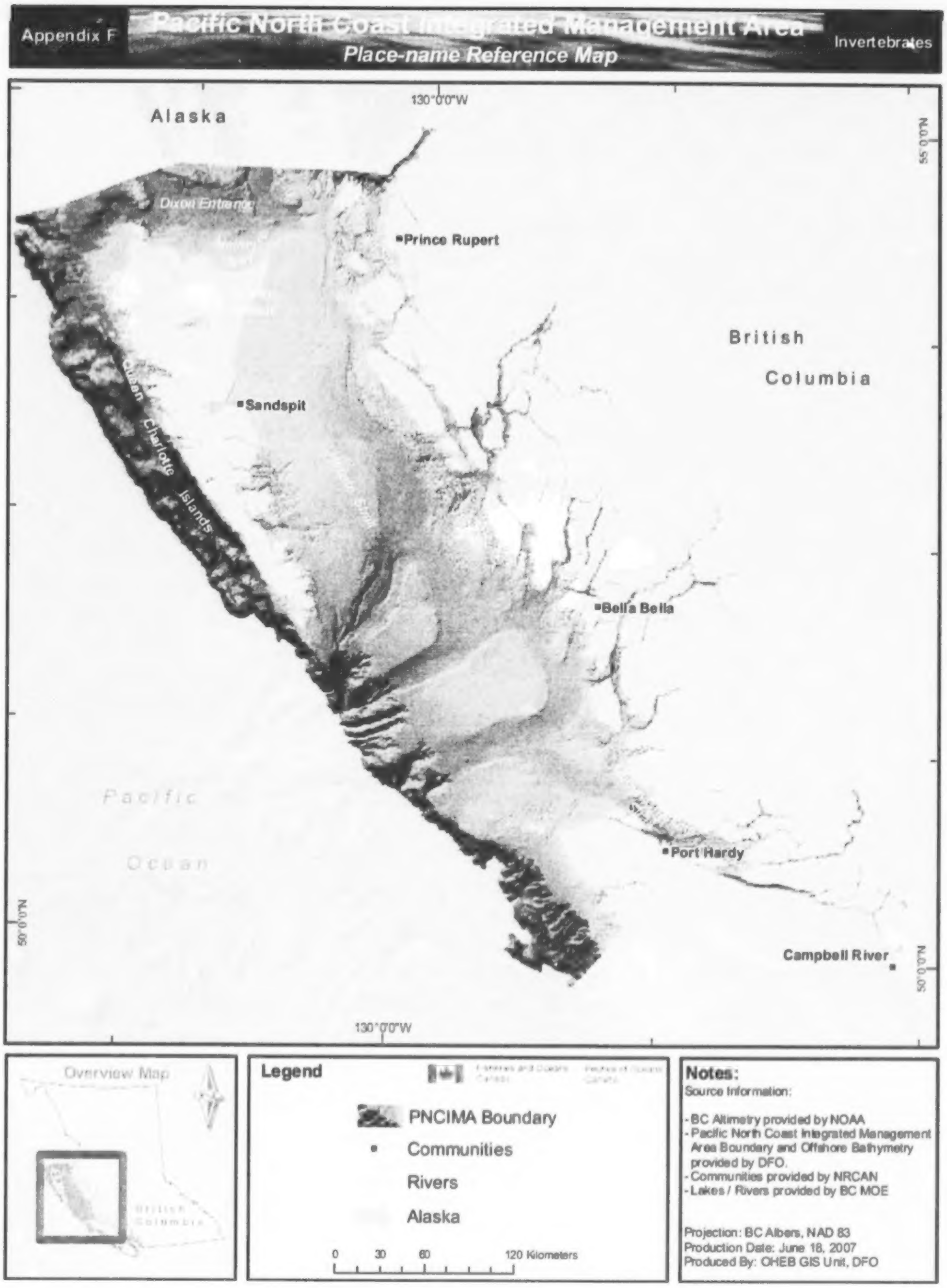
Appendix F
Pacific North Coast Integrated Management Area
Place-name Reference Map
Invertebrates
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Dixon Entrance
Prince Rupert
British Columbia
Sandspit
Queen Charlotte Islands
Bella Bella
Pacific Ocean
Port Hardy
Campbell River
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Rivers
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure F.0 PNCIMA region showing locations and features of BC waters.

2.0 SPONGES (PHYLUM PORIFERA)

2.1 Biology, Habitat & Ecosystem Linkages

In the North-eastern Pacific Ocean, between central California and southern Alaska, approximately 260 species of sponges are known, of which 7 are rare (Austin 1985). Of the three living classes of sponges (Calcarea, Hexactinellida and Desmospongiae), representatives of each class are found in the PNCIMA area. The location of few well known sponge occurrences is mapped (Chapter 2 Habitat, Map 2.1), but this by no means describes the full extent of their distribution or habitat usage in the area.

Sponges are encountered on a wide variety of substrates from soft mud and sand, to shells, corals, submerged timbers, rocky outcrops, and vertical rock walls (Austin 1985; Ruppert and Barnes 1994; Blake and Scott 1997e). Sponges are sessile organisms, forming unique three-dimensional living habitat structures and occupying area from the intertidal to the deep sea abyss, including seamounts. Sponges take on a variety of growth forms, which appear to be an adaptive response to localized environmental constraints (space, substrate and water currents)(Ruppert and Barnes 1994).

Sponges are capable of reproducing both asexually and sexually, including the ability to brood eggs and release flagellated larvae. They are also able to regenerate themselves after they have been broken or injured (Ruppert and Barnes 1994). There is limited information on the growth rates of the various species of sponges but a few studies are beginning to document this information (Leys *et al.* 2004).

Sponges have internal canal systems that continually filter water, providing a constant flow of food items, from dissolved organic matter to bacteria. As such, sponges' direct interaction with their external environment leaves them vulnerable to the absorption of harmful particles (Austin 1985; Ruppert and Barnes 1994; Blake and Scott 1997e; Lamb and Hanby 2005). Some sponges have acquired the ability to arrest feeding when their surrounding environment has high levels of silt or sediment (Leys *et al.* 2004). However, excessive amounts of sediment may lead to the smothering of the animal and result in death.

Sponges are preyed upon by nudibranchs, chitons, limpets, gastropods and sea stars (Blake and Scott 1997e; Lamb and Hanby 2005).

In PNCIMA, the best known sponge locations are associated with the hexactinellid sponge reefs, which at the time of discovery attracted world-wide attention. The existence and formation of these sponge reefs requires a combination of a unique geological setting (as described in Appendix A: Geology) along with the occurrence of particular Hexactinellida sponge species (Conway 1999; Department of Fisheries and Oceans 2000c). Hexactinellida are typically found in deep water and prefer habitats with high dissolved silica levels, low light levels, cold temperatures and substrates with little to no sediment accumulation (Leys *et al.* 2004). The bioherms, or reefs, created are known to attract a multitude of other invertebrate animals such as tunicates, sea stars, brittle stars, gastropods, polychaetes, amphipods and arthropods (*i.e.*, shrimp, crabs and barnacles). Various fish species have also been noted to use the three-dimensional rigid structures as refugia for themselves and to lay their eggs (Smith and Carlton 1975).

2.2 Status & Management

The fragile nature of sponges makes them highly susceptible to damage from physical impacts. Anthropogenic influences having benthic contact, such as fishing gear (Etnoyer and Morgan 2003), seabed mining, and cable laying, and ones causing sediment deposits, such as paper mills, mines, and aquaculture, can result in extensive sponge damage and mortality. The greatest impact to sponges appears to be from multiple years of high intensity bottom trawl fishing. Fishery management measures have been implemented in the PNCIMA area to preserve known existing reef-forming Hexactinellida sponges (approximately 1000 km^2).

In terms of habitat management issues, large sponge concentrations are considered critical and sensitive areas. To avoid these areas, habitat managers will need to work with industry, for example, to carrying out site evaluations at aquaculture leases.

To date, there has been no commercial harvesting of sponges in British Columbia. The BC Conservation Data Center has "red" listed the Cloud Sponge, *Aphrocallistes vastus* (a Hexactinellida) but this status lacks any means of protection. There are no species listed at this time under SARA legislation.

Sponges can also become a pest, for example within the Demospongiae, there is a shell-burrowing sponge (*Cliona* spp.), which can potentially cause mortalities to oysters, mussels and scallops. To date, aquaculture sites in PNCIMA have yet to note any devastating effects and therefore no management actions have been taken.

2.3 Information Gaps, Uncertainties, Limitations & Variability

There is little or no information on sponges from which to define population trends for these animals in the PNCIMA. To date, the majority of information on sponge distribution has come from data collected during non-directed studies or from commercial trawl bycatch monitoring. Significant information gaps exist for this phylum, partly due to the lack of consistent taxonomic classification and proper identification of species. Identification of sponges is difficult due to: (1) many undescribed species, (2) limited taxonomic literature and (3) historic taxonomic problems (Austin 1985; Ruppert and Barnes 1994; Blake and Scott 1997e). Without this basic information about species present, other questions relevant to management of these species can generally not be addressed.

3.0 HYDROIDS, ANEMONES, SEA PENS, SEA WHIPS, CORALS AND JELLYFISH (PHYLUM CNIDARIA)

3.1 Biology, Habitat & Ecosystem Linkages

Hydroids (Hydrozoans), anemones, sea pens, sea whips, and corals (Anthozoans) and jellyfish (Schyphozoans) are animals that all have a consistent and simple body structure and are taxonomically classified together under the Phylum Cnidaria (Ruppert and Barnes 1994). Cnidarians may be either sessile or mobile as well as either solitary or as part of a colony. They inhabit soft and rocky substrates or are pelagic, from intertidal to deep-sea environments and are found in both infauna and epifauna communities (Bertness *et al. eds*. 2001). Cnidarians exhibit two body forms, one adapted for pelagic existence and the other adapted for an attached, benthic existence.

Almost all cnidarians are carnivorous, feeding on small fishes, crustaceans, oyster spats, larvae and other such organisms (Smith and Carlton 1975; McLachlan and Ayres 1979; Ruppert and Barnes 1994). Mobile species are typically predators seeking out prey, while sessile cnidarians require a continual flow of water in order to bring prey within their reach. Predators on the sessile forms of these animals include sea stars and nudibranchs while other planktonic animal forms are preyed upon by higher tropic organganisms such as fish and marine mammals (McLachlan and Ayres 1979).

Typical developmental period of cnidarians is highly variable, with some taking up to a full year to complete while others develop rather quickly into ciliated larvae or free-swimming sexual medusa (Johnson and Snook 1955; Smith and Carlton 1975; McLachlan and Ayres 1979). Mobile larvae lead to effective distribution of the species. This larval phase may last for a few days to just a few hours before settlement occurs on substrates, where development into adult forms takes place (Johnson and Snook 1955; McLachlan and Ayres 1979). The life span for a few pelagic species is only a year and evidence of this is seen on beaches littered with remains (Smith and Carlton 1975; McLachlan and Ayres 1979), while some coral species are believed to live for hundreds of years.

Of special note in the PNCIMA region are cold-water corals, occupying substrates between the intertidal and deep sea. Like sponges, corals create vertical relief through the formation of three-dimensional living habitat structures. Cold-water coral structures range from small, solitary individuals to large colonial grove and reef habitats. The location of known coral occurrences is mapped in (Chapter 2 Habitat, Map 2.1) but by no means describes the extent of their habitat range. Corals may be referred to as foundation species since they play an important role as habitat modifiers, altering patterns of water, movement and influencing food and larval supply (Bertness *et al. eds*. 2001). The complex branching morphology of many corals creates structures of sufficient size to provide substrate or refuge for other animals (Etnoyer and Morgan 2003). Similar to sponges, live and dead portions of a coral's matrix or lattice framework are used to create substrates and shelter for other corals, sponges, brachiopods, bivalves, crustaceans, bryozoans, crinoids and tunicates (Hall-Spencer *et al.* 2002; Koslow *et al.* 2001).

3.2 Status & Management

To date, these animals are not considered in any fisheries or habitat management strategies, with the exception of corals. Similar to other structural forming invertebrates, anthozoans in PNCIMA are capable of forming extensive structural habitats. The fragile skeletons and upright growth forms make them vulnerable to physical impacts. Similar to sponges, anthropogenic influences having benthic contact (fishing gear, seabed mining, cable laying, etc.) can result in extensive mortality. An initiative to develop a conservation strategy for corals and sponges is in progress.

3.3 Information Gaps, Uncertainties, Limitations & Variability

Detailed life history studies are particularly needed for many Cnidarians. There is currently the possibility of taxonomic problems associated with these animals, where the polyp and medusa stages of the same animal have been described under separate names (Smith and Carlton 1975).

To date, there have been very few research initiatives on these animals in British Columbia. Knowledge of their identity, spatial occurrence, general biology, regeneration abilities and ecosystem significance is limited. Recent synoptic surveys in PNCIMA have discovered new species and new records of species of Anthozoans never before encountered from our waters.

4.0 BRYOZOANS (PHYLUM BRYOZOA)

4.1 Biology, Habitat & Ecosystem Linkages

Bryozoans are very small animals that have a unique food-catching structure composed of tentacles surrounding the mouth called a lophophore (Ruppert and Barnes 1994). Bryozoans are common and abundant colonial animals, commonly known as moss animals, often overlooked due to their very small individual size (approx 0.5 mm) and resemblance to organisms such as hydroids, corals, sponges or seaweeds (Lamb and Hanby 2005). Between 230 and 300 species of the world's 5000 living species of bryozoans are found from central California to southern Alaska (Austin 1985; Ruppert and Barnes 1994; Soule *et al.* 1997; Sloan *et al.* 2001; Lamb and Hanby 2005). Many species are widely distributed and found at all depths, although bryozoans are most abundant in the intertidal (littoral) and the shallow sub-tidal (neritic) zones (Austin 1985; Smith and Carlton 1975; Ruppert and Barnes 1994; Soule *et al.* 1997).

Bryozoans are another phylum capable of forming living habitat structures. Hundreds to thousands of independent individuals live as members of large, structured communities (Ruppert and Barnes 1994; Soule *et al.* 1997). Bryozoans flourish in nearly every marine environment and are often found on surfaces of algae, worm tubes, sponges, shells, rocks, corals, pilings and sandy beaches (Smith and Carlton 1975; Ricketts *et al.* 1968; Ruppert and Barnes 1994; Soule *et al.* 1997; Lamb and Hanby 2005). Encrusting bryozoans are found in turbulent or exposed waters, where they will often take on the form of their substrate. In protected waters, erect forms attach to the substrates by 'roots' or basal discs and often resemble lichens, chicken-wire or long tubes (Smith and Carlton 1975; Ruppert and Barnes 1994; Soule *et al.* 1997). Depending on environmental conditions, bryozoans take on variable forms, often making them difficult to identify (Smith and Carlton 1975; Soule *et al.* 1997). Within the ecosystem, bryozoans provide shelter and habitat for numerous other species, including brittle stars and polychaete worms (Ricketts *et al.* 1968; Lamb and Hanby 2005).

Bryozoans are suspension feeders, making them completely reliant on water currents to bring them nutrients (tiny algae, bacteria and detritus). Considering the continuous intake of water, the health of bryozoans may provide indications of changing water quality (McLachlan and Ayres 1979; Lamb and Hanby 2005). Due to their very diverse forms, there is a range of predator/prey relationships for bryozoans in the marine environment. Some bryozoans are preyed upon by crabs, limpets and nudibranchs, while others are able to defend themselves against settling larvae and larger organisms (Ricketts *et al.* 1968; Ruppert and Barnes 1994).

Bryozoans release their fertilized eggs, or developed mobile larvae, into the water column. Once the animal settles and attaches to a surface, the colony formation takes place by means of asexual budding (Ruppert and Barnes 1994; Blake and Scott 1997a; Lamb and Hanby 2005). Bryozoans are also able to go through phases of degeneration and regeneration, making them adaptable to changes in oceanographic conditions. They are one of the most abundant marine epifauna (Ruppert and Barnes 1994).

4.2 Status & Management

Despite their adaptable nature, bryozoans are susceptible and vulnerable to destructive habitat practices as well as other substrate-disturbing activities. These types of activities have the potential to result in limiting available suitable surfaces for settlement.

Economically, some bryozoans can be major fouling organisms that take over available substrates, thus impacting on ecosystems as a whole, *e.g.*, bryozoans are one of the most important groups of organisms to foul the hulls of ships.

When managing animals within this Phylum, there may be a need to protect certain species and their habitats (*e.g.*, habitat forming structures such as coral-like bryozoans), while at the same time, consideration must be given to controlling pathways that distribute these animals due to their ability to potentially cause various economic hardships. Two known species have been introduced to the Pacific Northwest, including the well-adapted orange encrusting bryozoan (*Schizoporella unicornis*), which was likely introduced from Japan with the Pacific oyster (Lamb and Hanby 2005).

4.3 Information Gaps, Uncertainties, Limitations & Variability

At this time, there is a lack of information on bryozoans in British Columbia to describe what we have, where they are distributed and any population trends in PNCIMA. There is a lack of taxonomic expertise and tools to readily identify what we have and therefore there are no directed programs to collect the kind of detailed information required to address the above-mentioned management issues.

5.0 SEA STARS, BRITTLE STARS, BASKET STARS, SEA CUCUMBERS, SEA URCHINS, AND SAND DOLLARS (PHYLUM: ECHINODERMATA)

5.1 Biology, Habitat & Ecosystem Linkages

Echinoderms are exclusively marine and relatively large animals (at least several centimetres in diameter), characterized by a five-part radial symmetry. The name means 'spiny-skinned' and most of the species have either a granulated or hard calcareous outer covering or calcareous ossicles hidden in the skin (Ruppert and Barnes 1994). They have a distinctive water vascular system, with a single opening and an internal plumbing system of interconnected canals (Lamb and Hanby 2005), which in many echinoderms has become a means to move their tube feet, arms or spines (Ruppert and Barnes 1994).

In the Pacific Northwest, there are approximately 280 to 300 echinoderm species documented (Austin 1985; Lamb and Hanby 2005) out of over 6000 known species (Ruppert and Barnes 1994). The Pacific Northwest has the greatest concentration of sea star species in the world, including 70 endemic species around Vancouver Island (Ruppert and Barnes 1994), in the southern portion of PNCIMA.

Echinoderms are usually found on the bottom during their adult life, but their habitat preferences range considerably, due to their diversity in form and life history characteristics. Some echinoderm species are able to avoid desiccation within the intertidal zone, while others withstand significant pressure at great depths (>4300 m). Some echinoderms can secure themselves onto hard substrates in high current areas, while others bury themselves in sand and mud (Ruppert and Barnes 1994; Bertness *et al. eds*. 2001; Lamb and Hanby 2005). In PNCIMA, some species of sea cucumbers prefer eelgrass habitats, while other sea cucumber species inhabit mussel beds (Lambert 1997). Some sea cucumber species have a specific known distribution range, such as the intertidal tiny black sea cucumber (*Cucumaria vegae*) found only north of the Queen Charlotte Islands (Lamb and Hanby 2005) occupying only a small portion of PNCIMA. Giant red sea cucumbers (*Parastichopus californicus*), found in depths ranging from intertidal to 250 m (Lamb and Hanby 2005), can be found on most substrate types but show preferences for hard substrates and are least abundant on mud and silt (Woodby *et al.* 2000). Sea urchins often have a distinct upper limit to their vertical distribution and some species are concentrated close to the upper limit of their distribution (Jamieson and Francis 1986). Some echinoderms, such as green sea urchins (*Strongylocentrotus droebrachiensis*) are more mobile than a similar species, red sea urchins (*S.*

franciscanus), because they make seasonal migrations between deep and shallow waters (Stocker *et al. eds*. 2001). In general, echinoderm species aggregate, resulting in significantly high population densities in areas with favourable conditions, related to available food and specific reproduction temperatures (Lamb and Hanby 2005).

Most echinoderms are dioecious, with external fertilization (Ruppert and Barnes 1994). For most, the breeding season occurs in the spring to summer and appears to be triggered by environmental factors such as the number of days of bright sunshine, the presence of phytoplankton blooms, and warming water temperatures (Cameron and Fankboner 1986). Urchin spawning season is species specific: green urchins spawn between February and March; red urchins spawn between March and September; while purple urchins (*Strongylocentrotus purpuratus*) spawn between October and December. Generally, the fertilized eggs quickly develop into free-swimming planktonic larvae with various degrees of dispersal, and eventually undergo metamorphosis and settle to the bottom (Ruppert and Barnes 1994). For settled juvenile urchins, their recruitment success tends to be highest where large numbers of adult urchins are present, as the spines of the adults provide protection from predators (Stocker *et al. eds*. 2001). Urchins reach maturity within their first few years and have relatively long life spans of 30 years or more (Ruppert and Barnes 1994).

Echinoderms as a whole have widely diverse feeding habits, including herbivores, carnivores, scavengers, deposit or suspension feeders (Ruppert and Barnes 1994). Sea stars and brittle stars are considered to be relatively major predators. They have adapted on a species-by-species basis to feed on a variety of species including zooplankton, sponges, anemones, hydroids, corals, bryozoans, snails, bivalves, crustaceans, polychaetes, other echinoderms and small fishes (Ruppert and Barnes 1994).

Sea cucumbers are called "cleaners of the benthos" since they use their feeding tentacles to gather up suspended or deposited decaying matter (Jamieson and Francis 1986; Lamb and Hanby 2005). This feeding habit keeps substrates available to settling larvae and fulfills a very important niche by recycling nutrients. Basket stars, feather stars and crinoids are suspension feeders, which are commonly found attached to sponges and corals in order to gain better access to plankton. Sea urchins feed by scraping the surface of substrates on which they live, while seeking out a variety of both plant and animal matter for their diets (Ruppert and Barnes 1994; Lamb and Hanby 2005). Some urchins play a critical roll as grazers in algal habitats and are considered to be keystone species, as they can alter the ecosystem that they live in. Where few predators exist, urchin populations can completely overtake their algal food source, causing a resultant habitat commonly named "urchin barrens" (Lamb and Hanby 2005).

Predators have various effects on echinoderms, including the ability of echinoderms, when stressed, to degenerate and self-amputate or autotomize body parts. While some sea stars loose their arms, many sea cucumbers eject parts of their viscera and associated organs while under attack or distressed (Ruppert and Barnes 1994). Regeneration of lost body parts can range in time from a few days up to a year. This ability to regenerate body parts is likely an important characteristic contributing to the success of echinoderms (Ruppert and Barnes 1994; Lamb and Hanby 2005).

There are a variety of predators on echinoderms, including a sea star, and linking to terrestrial food webs where bears and birds scour the intertidal and feed on such organisms. There is also a demand for echinoderms for human consumption, including traditional First Nations' use, as well as commercial ventures. A well documented ecological relationship exists between sea urchins (prey for otters, consumer of kelp), sea otters (predator on sea urchins) and kelp beds (food for sea urchins) (Estes *et al.* 1978; Breen *et al.* 1982; Duggins 1980; 1983; Jamieson and Francis 1986; Schroeter *et al.* 1996).

5.2 Status & Management

At this time there are three species of echinoderms (one sea cucumber and two sea urchins) that have directed commercial fisheries in the PNCIMA area. The giant red or California sea cucumber (*Parastichopus californicus*) dive fishery expanded north into PNCIMA in 1987, and presently 95 % of the coast wide total allowable catch (TAC) is extracted from there. The fishery is managed by quotas, which are derived from a fixed exploitation rate, and biomass estimates set at conservative levels based on shoreline length (Boutillier *et al.* 1998) or through assessment dive surveys. The fishery also has area restrictions with current commercial harvesting limited to 25 % of the BC coastline, while the remaining portion includes 25 % set aside for research and experimental fisheries and 50 % closure (DFO 2002). Although this fishery is believed to be very precautionary and sustainable, there are concerns regarding localized stock depletion from harvesting pressures (Humble *et al.* 2006). The ability and time it takes for sea cucumbers to recover is not fully understood (Stocker *et al. eds*. 2001), however this is being addressed in some of the experimental fisheries that are testing various exploitation rates (Hand and Rogers 1999) and depletion/recovery experiments to specifically examine recovery dynamics (C. Hand, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2006).

Depending on the species, commercially harvested urchin stocks are either considered stable (red urchins) or appear to be rebuilding (green urchins) from past fishery pressures (DFO 2001c; 2003). These fisheries are managed on a quota, based on a fixed exploitation level with biomass levels set through assessment dive survey or extrapolation from the nearest survey and logbook information.

From an ecosystem management perspective the re-introduction of sea otters in PNCIMA will present managers with a new set of challenges, as there will be major conflicts between the management of the recovery of the SARA-listed sea otter and access to sea urchins for First Nations and commercial needs and wants. We have already seen decreased purple urchin abundance and increased algal biomass attributed to the recovery of the sea otter in PNCIMA (Workman 1999).

5.3 Information Gaps, Uncertainties, Limitations & Variability

Despite their significant presence in PNCIMA, there have been no directed research or management implementations for non-commercial species of echinoderms. The biology, life history and role of many non-commercial echinoderms in the Pacific Northwest ecosystems remain unknown.

6.0 FLATWORMS (PHYLUM: PLATYHELMINTHS)

6.1 Biology, Habitat & Ecosystem Linkages

Globally there are about 20,000 species of flatworms (Platyhelminthes), most of which belong to three parasitic classes and a third class, known as free-living flatworms (Turbellaria) consisting of approximately 3000 species (Ruppert and Barnes 1994; Blake and Scott 1997a; Lamb and Hanby 2005). In the Pacific Northwest, there are approximately 126 identified species of Turbellaria but this by no means represents the extent of this group in the Pacific north west coast (Austin 1985; Lamb and Hanby 2005). The known species in this area range in size from 1.2 cm to 6 cm, with larger flatworms commonly found under rocks, on wharf pilings, attached to algae or associated with other invertebrates (Ruppert and Barnes 1994; Blake and Scott 1997a; Lamb and Hanby 2005). Their body colouration commonly resembles their surroundings, making them often difficult to detect in nature. There is great diversity in flatworms, including many of the smaller unknown species being microscopic interstitial forms and likely part of the meiofauna (Blake and Scott 1997a). Turbellarians have a wide variety of locomotory adaptations and are capable of living in soft sediment with low levels of oxygen (Ruppert and Barnes 1994; Lamb and Hanby 2005).

Flatworm reproduction appears to be controlled by day length and temperature. Primarily, sexual reproduction takes place, producing a small number of eggs that undergo direct development and contribute to the plankton community for a short time as meroplankton (McLachlan and Ayres 1979; Ruppert and Barnes 1994). Little is known about the prey of turbellarians but the organism itself may be parasitic or have commensal relationships (Lamb and Hanby 2005). Species will commonly parasitize the guts and body cavities of molluscs, crustaceans, echinoderms and the skin of fishes while other species co-exist in the mantle cavities of molluscs and gills of crustaceans (Ruppert and Barnes 1994). Flatworms are quite versatile, having close to an unlimited capacity for adaptability and as a result, ecologically are very successful (McLachlan and Ayres 1979).

6.2 Status & Management

The only management issue that may be of concern at this time in PNCIMA is related to the expansion and movement of shellfish aquaculture products. During the initial oyster boom on BC's coast in the 1930s, a species of turbellarians, the bivalve flatworm

(*Pseudostylochus ostreophagus*), was introduced and became a predatory pest at local shellfish aquaculture sites. Whether or not this occurs in PNCIMA has yet to be confirmed. However, recent observations have suggested habitat ranges show significant northward extensions for a number of native species (Lamb and Hanby 2005). A risk assessment of the pathway vectors for the spread of these parasites may need to be undertaken and managed accordingly.

6.3 Information Gaps, Uncertainties, Limitations & Variability

Due to difficulty in identifying platyhelminthes in their natural environment, many species are believed to be undiscovered and unrecorded at this time.

7.0 SEGMENTED WORMS AND LEECHES (PHYLUM: ANNELIDA)

7.1 Biology, Habitat & Ecosystem Linkages

There are 3 classes of annelids, of which only two with marine life histories will be outlined, marine leeches (Class Hirudinnea) and polychaete worms (Class Polychaeta). In the Pacific Northwest, there are 11 known species of marine leeches and over 850 known polychaetes (Austin 1985; Smith and Carlton 1975; Blake *et al.* 1997; Lamb and Hanby 2005). Polychaetes, particularly those on our continental shelf and slope, typically comprise 45 to 50% of the total number of species and up to 80% of the total number of individuals in benthic communities (Smith and Carlton 1975; McLachlan and Ayres 1979; Ricketts *et al.* 1968; Ruppert and Barnes 1994; Blake *et al.* 1997; Bertness *et al. eds*. 2001; Lamb and Hanby 2005).

Polychaetes inhabit a variety of substrates, from the intertidal zone to the abyss (Johnson and Snook 1955; Smith and Carlton 1975; Kozloff 1996; Blake *et al.* 1997; Bertness *et al. eds*. 2001). There are sedentary as well as free-living forms capable of swimming, crawling, burrowing, boring and constructing temporary and permanent tubes (Johnson and Snook 1955; Smith and Carlton 1975). Borer species are important in that they break-up hard substrates (shells, rocks, etc.), contribute to the production of sand, and assist in the creation of soft substrate habitats. Burrowing species stabilize sediments and create water vortices, recycling nutrients within the seabed as well as vertically into the water column (Blake *et al.* 1997; Lamb and Hanby 2005). Additionally, burrowers play an important role aerating sediments by moving more oxygenated surface waters to the often anoxic sediments (Blake *et al.* 1997). Burrowing polychaetes have a major role in defining the characteristics of the top layers of the sediments as well as the fundamental structure of the associated community.

Healthy polychaete communities represent major contributions to marine and terrestrial food webs (Lamb and Hanby 2005). Adult polychaete populations are consumed by predators such as other polychaetes, sea stars, molluscs, arthropods, demersal fish, grey whales, shorebirds and humans, while their larvae are a prime food source to zooplankton, fish and baleen whales (Lamb and Hanby 2005; McLachlan and Ayres

1979). Surviving predation and depending on the extent, some polychaetes (*Chaetopterus* spp., *Dodecaceria* spp.) possess the unique ability to regenerate their entire body from a single segment while other polychaete species have varying, but still remarkable, ability for regeneration (Ruppert and Barnes 1994). Predation and other pressures are often the limiting factors of organisms burrowed in the bottom sediments (infaunal populations) (Ruppert and Barnes 1994). The ability to survive predation and regenerate lost body parts gives a definite competitive advantage to polychaetes over other organisms in the same environment. Modes of feeding are closely tied to habitats, errant polychaetes or free-living species can be significant predators and tend to be raptorial carnivores, omnivores or scavengers, while sedentary polychaetes or burrowers and tube dwellers tend towards deposit and filter feeding (Johnson and Snook 1955; McLachlan and Ayres 1979; Blake *et al.* 1997; Bertness *et al. eds*. 2001). Feeding methods are quite variable including the formation of mucus "bags", branchial plumes, "branches" and well developed horny jaws used to capture plankton, small invertebrates (hydroids, sponges, bryozoans, tunicates, echinoderms, molluscs, and crustaceans), detritus and various algal species (Ruppert and Barnes 1994; Blake *et al.* 1997).

This phylum is diverse, including parasitic marine leeches found attached to fishes, particularly flatfish and various invertebrates, as well as other non-parasitic polychaetes (Blake *et al.* 1997; Lamb and Hanby 2005). Mutualistic polychaetes are found associated with a variety of animals, from sessile invertebrates (sponges, corals and bryozoans) to mobile species, such as sea cucumbers, sea stars, snails, chitons, limpets, and within crab branchial cavities. In the mutualistic relationship, which benefits both species, the polychaete hitches rides to new habitats or gains access to food, while the host may be defended by the aggressive acts of the polychaete (Smith and Carlton 1975; Lamb and Hanby 2005; Blake *et al.* 1997).

Polychaetes exhibit more diversity in modes of reproduction and development then any other invertebrate taxa (Johnson and Snook 1955; Lamb and Hanby 2005; McLachlan and Ayres 1979; Ruppert and Barnes 1994; Blake *et al.* 1997). Timing of reproduction may be tied with lunar cycles, tidal fluctuations, temperature, day length, light intensity and salinity (Lamb and Hanby 2005; Blake *et al.* 1997). For some species, spawning may terminate their life cycle, while others are able to reproduce multiple times and alternate between phases of sexual and asexual cycles (Blake *et al.* 1997). Polychaete larvae may spend hours to months drifting in tides and currents until they are triggered by a biochemical or sediment response to migrate to the benthos (Blake *et al.* 1997; Lamb and Hanby 2005).

7.2 Status & Management

In benthic communities, successful opportunistic species such as polychaetes are a good indicator species of changing levels of organic matter (Blake *et al.* 1997). This is an important consideration when studying the implications of anthropogenic disturbances which drastically alter sediments and exposure. Polychaetes are known to rapidly recolonize and rehabilitate areas exposed to waste-water disposal, oil spills, aquaculture-generated wastes and even areas damaged by severe oceanic storms (Lamb and Hanby

2005). On the other hand, polychaetes may become a pest to aquaculture (*i.e.*, oysters) as they are capable of excavating portions of shells allowing for localized accumulation of mud and sediment. As a result, "mud-blisters" form, causing a reduction in the market value for these cultured species (Blake *et al.* 1997).

7.3 Information Gaps, Uncertainties, Limitations & Variability

There are no assessment or management plans for benthic communities, yet a healthy diverse benthic community is a basic building block to healthy, stable, diverse, and productive marine ecosystems. Polychaetes are one of the most important components of the benthic community, as seen from what we know about their diversity, their interactions with other organisms, their adaptability, and their ability to recolonize previously disturbed sediments.

There has been previous work on the taxonomy of polychaetes throughout the world, but not focused on PNCIMA. In 1985, there were an estimated 836 polychaete worms described for the Pacific Northwest. However, there are new species continually being discovered and described (Lamb and Hanby 2005). These rapid developments have resulted in the taxonomy of polychaetes in the Pacific Northwest to be in a state of flux, as there are no directed scientific investigations focussed on these animals or the benthic community as a whole.

8.0 CLAMS, MUSSELS, SNAILS, ABALONE, OCTOPUS, SQUID, AND RELATED ANIMALS (PHYLUM: MOLLUSCA)

8.1 Biology, Habitat & Ecosystem Linkages

This large and conspicuous group contains such diverse organisms as gastropods (snails, limpets, nudibranchs), bivalves (clams, mussels, scallops, oysters), cephalopods (octopus and squid) and chitons. In the Pacific Northwest, there are well over 1400 species in this phylum, including over 900 gastropods, close to 400 bivalves and 60 cephalopod species (Austin 1985; Lamb and Hanby 2005; Scott and Blake 1997; McLean and Gosliner 2006). Molluscs are an important component of intertidal biota and often dominate organism diversity in many habitats (Ricketts *et al.* 1968). Molluscs are found from the intertidal to deep ocean trenches, on protected and exposed shores as well as associated with deep sea hydrothermal vents (Scott and Blake 1997; McLean and Gosliner 2006).

Life history characteristics and reproductive habits vary among molluscan classes. Most molluscs are dioecious and most require warming water temperatures to trigger spawning. A notable exception to this in BC is opal squid, which spawns between December and September with two major peaks of activity happening in March and July. Commercial landings of opal squid have been documented in PNCIMA (Walthers and Gillespie 2002). Spawning aggregations have been reported from a number of areas including the west coast of the Queen Charlotte Islands, Hecate Strait, and in Queen Charlotte Strait (G.E. Gillespie, DFO, Pacific Biological Station, Nanaimo BC, pers.

comm., 2006). Most bivalves have external fertilization, where the eggs and sperm (gametes) are released outside the body for fertilization in seawater (broadcast spawning) and development through planktonic larval stages. Some gastropods are broadcast spawners, while others have internal fertilization, with copulation and nurturing of fertilized eggs inside the adult body cavity (Ruppert and Barnes 1994). Some molluscan species produce extensive egg masses that may be contained in a case, in ribbons or housed inside the mantle cavity of adults during early life stages and then released to surrounding seawater (Jamieson and Francis 1986; Lamb and Hanby 2005). Planktonic larvae disperse in water currents and eventually settle on suitable substrate, where some may remain for life (Jamieson and Francis 1986; Lamb and Hanby 2005; DFO 2004). The life span of some species such as octopus and squid is determined by spawning activity, where females spawn only once (Jamieson and Francis 1986; Ruppert and Barnes 1994; Lamb and Hanby 2005). Growth rates vary among species, but are known to be relatively rapid during the first few years while being influenced by habitat and local environmental conditions (Jamieson and Francis 1986; Lamb and Hanby 2005). Species such as abalone and geoduck are slow growing and long lived, resulting in a large portion of their spawning stock of older and larger individuals.

In general, gastropods creep over and graze the surfaces of hard substrates and marine plants (Ruppert and Barnes 1994; Lamb and Hanby 2005). Many gastropods are herbivores or algae eaters, grazing on kelp and sea grass. Herbivorous molluscs may be impacted by the potential loss of marine plants along the coast, as food availability would be greatly reduced along with the loss of habitat and as a result, would increase their exposure to predators (Lamb and Hanby 2005).

As an exception to most molluscs, cephalopods are active predators, feeding mainly on crustaceans, other molluscs, worms and fishes. Cephalopods are a major component of the diets of toothed whales, pinnipeds (seals and sea lions), marine birds and larger fishes (Jamieson and Francis 1986; Ruppert and Barnes 1994). Predator-prey relationships may vary for particular species of cephalopods since many migrate vertically in the water column between seasons, while others travel on route from southern latitudes northwards, in order to reach feeding grounds at subarctic boundaries. Some species of cephalopods that typically aggregate along cold-water fronts are found in PNCIMA only at particular times of year.

Many molluscs are found in association with other organisms. Bivalves can occur in commensal relationships with sponges, cnidarians, polychaetes, crustaceans, echinoderms and ascidians. Some of these organisms provide protection, shelter and a food source for the mollusc, while they in turn are provided with an expanded water flow and food supply (Lamb and Hanby 2005; Scott and Blake 1997; McLean and Gosliner 2006).

Most clams are primarily suspension or filter feeders and their depths in the substrate are generally determined by the lengths of their siphon. With some species, clams' siphons are found in tunnels created by worms or shrimp, which enables the clam to exist deeper in the substrate than it could on its own (J. Dunham, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2006). Clam siphons provide water quality information for the organism and provide for the intake of water and food particles as well as the outflow of water and feces (Jamieson and Francis 1986; Lamb and Hanby 2005). There are a few clams, such as the varnish clam (*Nuttallaria obscurata*) that are selective deposit feeders as well. The foot is extended past the valves (shells) and rotated through the sediments, then material is passed to the oral region when the foot is retracted (Gillespie *et al.* 1999). A common invertebrate clam predator in PNCIMA is Lewis' moonsnail (*Euspira lewisii*), which also preys on other snails (Bernard 1967; Lamb and Hanby 2005). Other clam predators include sea stars (*Pisaster* spp.), crabs, diving ducks, gulls and crows (DFO 2001a; 2001d). In much of PNCIMA, clams are found at the heads of inlets where there is some deposition from river outlets, as well as in bays accumulating suitable clam substrates.

The major native bivalve species in PNCIMA include littleneck clams (*Protothaca staminea*), butter clams (*Saxidomus gigantea*), geoduck clams (*Panopea abrupta*), horse clams (*Tresus capax, T. nuttallii*), razor clams (*Siliqua patula*), cockles (*Clinocardium nuttallii*), Olympia oysters (*Ostrea conchaphila*), weathervane scallops (*Patinopecten caurinus*), spiny scallops (*Chlamys hastata*), pink scallops (*Chlamys rubida*), Pacific blue mussel (*Mytilus trossulus*) and California sea mussels (*Mytilus californianus*). There are numerous other bivalve species found throughout PNCIMA documented in a number of recent exploratory bivalve surveys (Gillespie and Bourne 1998; 2000; Gillespie *et al.* 2004a; Gillespie and Bourne 2005a; 2005b). Introduced or exotic bivalve species include blue or bay mussels (*Mytilus edulis*), Manila clams (*Venerupis philippinarum*) and varnish clams (*Nuttallia obscurata*).

Littleneck clams are likely the most abundant intertidal clam in PNCIMA. They are usually found in the mid to lower intertidal zone on every beach where there is suitable habitat consisting of mixed substrates of gravel, sand and mud (DFO 1999c; Gillespie *et al.* 2004a). Butter clams are widely distributed throughout PNCIMA, occurring on the lower third of the intertidal in mixed substrates. There are extensive populations with a wide range of sizes and age, indicating good recruitment and stability in the stocks (Gillespie and Bourne 1998; 2000; Gillespie *et al.* 2004a; Gillespie and Bourne 2005a; 2005b). The geoduck clam is one of the longest-lived animals in the world (well over 100 years), occurring throughout PNCIMA from the intertidal zone to depths of at least 110 metres. They are buried at least a metre deep in sand, silt, gravel and other soft substrates (DFO 1999c). Horse clams (mainly *Tresus capax*) are common throughout PNCIMA in the lower third of the intertidal zone (Gillespie *et al.* 2004a). Razor clams are found on sandy surf-swept beaches from the mid-intertidal zone to subtidal depths of 20 m at substrate depth of up to 25 cm. In PNCIMA, there is a large population of razor clams on Haida Gwaii at North Beach near Massett (DFO 2001b). Cockles are found throughout PNCIMA in the lower half of the intertidal, and very shallow in soft substrates. Cockles are particularly important to First Nations as a food source, especially on the North Coast (Gillespie and Bourne 2005a). Olympia oysters, a SARA-listed species, have been found in a few isolated areas of the PNCIMA, particularly in lagoons, where they remain continually immersed in water, even during low tide. Since lagoon habitats are fairly rare, these areas warrant particular attention. Weathervane scallop distribution is typically patchy throughout its range, but there is a notable population in Dixon Entrance, off the north coast of Haida Gwaii (Lauzier and Bourne 2006).

On high energy, wave-swept rocky exposed shores in PNCIMA, highly structured sea mussel beds provide habitat for nearly 300 other species. Sea mussels, *Mytilus californianus,* are a keystone species, providing a unique structure for a spatially highly complex community, often with several layers in the bed (Seed and Suchanek 1992; Suchanek 1979). The gooseneck barnacles (*Pollicipes polymerus*) are often interspersed in the mussels beds, forming a distinctive *Pollicipes-Mytilus* community (Lauzier 1999a; 1999b). Mussel growth rates are extremely variable, dependent on availability of food, intertidal elevation, temperature and mussel density (Gillespie 1999a; Jamieson and Francis 1986; Lamb and Hanby 2005). Sea mussels are long lived (50 to 100 years) and if greatly disturbed or destroyed, take from 5 to 100 plus years to recover to a climax community (Gillespie 1999a). The rate of recovery is dependant on the size, season and intensity of the disturbance, as well as predation by sea stars, whelks, fish, birds and marine mammals.

Over 35 species of molluscs have been introduced into BC waters, both intentionally and accidentally. Blue mussels, for example, were introduced via aquaculture and today have adapted into complicating hybrids (Lamb and Hanby 2005). The most successful introduced bivalve aquaculture product here in BC is the Pacific oyster (*Crassostrea gigas).* This species has recently been introduced into the PNCIMA area through the First Nations Turning Point initiative. Manila clams were inadvertently introduced to BC in the 1930s, with imported Japanese oyster seed, and the varnish clam was also inadvertently introduced into BC waters in the early 1990s. Both species are fairly widespread in the south coast, with reports of Manila clams in the central coast as far north as Laredo Inlet (52° 59'N) and varnish clams at the northernmost extent of Vancouver Island (Gillespie *et al.* 2004a). Manila clams have become the dominant clam in the commercial fishery in southern BC. They are harvested in PNCIMA where there are sufficient populations and where water quality testing programs are conducted. Due to their position high up in the intertidal zone, and their shallow substrate depths, Manila clams are particularly vulnerable to winter mortality, which can remove significant proportions of the population when frost is accompanied by night-time low tides (DFO 2001a). Varnish clams have spread rapidly through southern BC waters. They occur higher in the intertidal zone than Manila clams, but there is evidence of some overlap and competition between the two species (Gillespie *et al.* 2001). However, varnish clams are pedal-selective deposit feeders as well as suspension feeders (Gillespie *et al.* 1999), and occupy a slightly different niche than Manila clams.

8.2 Status & Management

Currently there are seven commercial mollusc fisheries in PNCIMA consisting of approximately twelve species.

The geoduck clam fishery began in BC in 1976, expanded to the north coast in 1980, and continues today to be one of BC's most valuable fisheries (DFO 2000b; Fisheries and

Oceans Canada 2002a; 2002d). The geoduck fishery is managed by quota, based on a fixed exploitation level applied against a bed abundance estimate based on survey and historic extrapolated log book information. Each geoduck bed has a limit reference point which does not allow the bed to be fished down below 50% of it's virgin density. Geoducks are harvested individually by divers with the use of a directed water jet or "stinger". The use of this gear is believed by some to disturb habitat, in particular exposing juvenile geoducks that are among older individuals to potential predators such as fish, crabs and sea stars (Jamieson and Francis 1986).

In the southern part of PNCIMA, there are adequate concentrations of pink and spiny scallops to support commercial fisheries. Due to a lack of information required to actively manage the fishery, the commercial fishery reverted to an experimental fishery to allow assessment and management frameworks to be developed as the fishery developed. The vast majority of the scallop fishery in PNCIMA is carried out using a unique scallop trawl (Fisheries and Oceans Canada 2000c; 2005; Lauzier *et al.* 2005).

Opal squid in BC are fished primarily as bait for the sablefish, crab and halibut fisheries, along with a small market interest as a food product. Opal squid landings are highly variable from year to year, with the late 1990's showing an increase in landings from the north coast (DFO 1999e; Fisheries and Oceans Canada 2006). It is not known whether the change in the pattern of landings is due to a change in squid distribution, markets, or other factors. Other squid species have had pilot fisheries in BC, but there is little information on available stock size, biological characteristics or fisheries interactions (DFO 1999d).

Another mollusc currently harvested under experimental licence is octopus (Fisheries and Oceans Canada 2000b).

In the late 1990's, there was a proposal to harvest sea mussels through the development of a fishery in PNCIMA. Following an evaluation, it was concluded that the fishery was undesirable due to a number of factors, including sea mussel longevity, their sensitivity to disturbances with their bed structures as "important reservoirs of biological diversity", as well as the keystone species role of the sea mussel (Gillespie 1999a).

Intertidal clam landings have been recorded since the turn of the century and have had great importance to First Nations peoples. In general, five species of intertidal clams comprise the major portion of commercial, recreational and First Nations landings coastwide (DFO 1999b; 1999c; 2001d; Fisheries and Oceans Canada 2000a). Razor clams are harvested only in PNCIMA where they occur in sufficient densities using a quota system based on a fixed exploitation rate applied against surveyed biomass estimates (DFO 2001b). Commercial harvesting of intertidal clams in PNCIMA primarily focuses on Manila clams due to market preferences. Other clam species are important and harvested by First Nations, including cockles, butter clams and littleneck clams. For the most part, the north coast has remained closed to commercial clam harvesting since 1963. Clam fisheries in PNCIMA include Joint Management Plans with the Council of Haida Nations and the Heiltsuk Tribal Council for specific areas in the north and central coasts. Many of the closures in the north coast are the result of concerns regarding water quality and paralytic shellfish poisoning, which potentially creates human health risks (Fisheries and Oceans Canada 2002e). Like many fisheries, commercially harvested intertidal clams are controlled by minimum size limits and total allowable catches (TAC). The TAC is set using a fixed exploitation rate applied to the most recent assessment survey stock biomass estimate of legal-sized clams. The minimum legal-size limit for clams is set to allow for the organisms to spawn at least once before they are subject to fishing pressure.

Two mollusc species, the Olympia oyster (*Ostrea conchaphila*) and Northern or pinto abalone (*Haliotis kamtschatkana*) are the only marine invertebrates currently listed under SARA. The Olympia oyster is designated Vulnerable (COSEWIC 2004). The animals are characterized as being small in size and slow growing, while unknowns include population size and trend estimates (Gillespie 1999b). As part of the SARA process, a management plan must be in place within three years after the listing of the species (due date is June 2008).

The abalone is listed as threatened. All fishing activities (First Nations, commercial and sports) for abalone remains closed due to conservation concerns since December 1990. Abalone surveys currently take place in PNCIMA and at this time are showing no evidence of abalone population recoveries (DFO 2004). Poaching continues to be a significant threat to the recovery of populations, as does the reintroduction of sea otters in the PNCIMA area. A recovery strategy and action plan has been drafted, but the effectiveness of enforcement and enhancement measures may ultimately determine whether the stocks will have the opportunity to recover (DFO 2004). A re-evaluation of the status of these animals is due in 2008.

8.3 Information Gaps, Uncertainties, Limitations & Variability

Considering the extent and diversity of the mollusc phylum, only a relatively few species that have been commercial fished or ones with harvesting potential, have been studied. Many of these species significantly contribute to various trophic levels as well as community structures, but many unknowns remain as to their particular roles and values in ecosystems.

9.0 PHYLUM: ARTHROPODA

9.1 Biology, Habitat & Ecosystem Linkages

Arthropods include more described species than the rest of the animal kingdom combined. There are three major divisions of arthropods or subphyla named Chelicerata, Crustacea and Uniramia. Considering their diversity, wide distribution, and high abundance, arthropods have succeeded in virtually every habitat supporting life and are often among the most prominent residents (Johnson and Snook 1955; Ricketts *et al.* 1968).

With more than 38,000 known species, the subphylum Crustacea includes the most familiar marine arthropods, such as shrimp, crab, barnacles, copepods, amphipods, etc. (Ruppert and Barnes 1994). Crustaceans are found in a variety of habitats from the intertidal zone, estuaries, bays and inlets to open ocean pelagic environments and the deep-sea abyss. Some barnacles, for example, are entirely sessile as adults and form a major component of intertidal communities (Ricketts *et al.* 1968). Adult prawns (*Pandalus platyceros*), although mobile, show limited migration activity and result in hundreds of localized adult stocks, while other shrimp species, such as pink shrimp (*P. jordani*), show substantial changes in distribution throughout the year (Stocker *et al. eds.* 2001; DFO 1999f). Many smaller crustaceans are inconspicuous and often intimately associated with organisms such as anemones, sponges and marine plants, in which they are able to conceal themselves (Lamb and Hanby 2005). Another example of species associations in a slightly different context involves hermit crabs. Hermit crabs have soft unprotected abdomens that require empty snail shells or other shelters for protection.

In the marine environment, the majority of crustaceans can be characterized as highly mobile benthic megafauna. One distinguishing characteristic is their chitinous exoskeleton. This provides protection and extreme strength while somewhat limiting their mobility. As adults, some arthropods are solitary dwellers and their success is mainly due to their preference to remain hidden in crevices, under rocks, in abandoned shells or by attaching debris to their exoskeleton in attempts to become camouflaged (McLachlan and Ayres 1979). Like other benthic invertebrates, some arthropod activities result in oxygen mixing at or in the bottom sediments, encouraging the development and enhancement of later successional stages (Bertness *et al. eds.* 2001). On the other hand, early successional stages provide foraging opportunities for crustaceans (shrimp and prawns) which are limited to consuming small epibenthic invertebrates (Bertness *et al. eds.* 2001).

The life history and biology is similar for most marine crustaceans (with the exception of habitat preferences and vertical migrations in the water column). Typically during the late spring, crustaceans grow incrementally by moulting or shedding. This moulting process may serve to recycle nutrients from benthic sediments back into invertebrate and fish communities (Phillips and Lauzier 1997). During this soft-shell period (a few weeks), newly moulted organisms become highly vulnerable to natural predation, injury and death (DFO 2000a).

Crustaceans can be suspension or deposit feeders, in addition to being significant predators and foragers in BC waters (Ricketts *et al.* 1968; Blake and Scott 1997b; 1997c; 1997d; Bertness *et al. eds.* 2001; Lamb and Hanby 2005; Johnson and Snook 1955; Butler 1980). They can also be parasites as we see in the parasitic barnacle, *Sylon*, which infects prawns and other shrimp in PNCIMA (Bower and Boutillier 1988).

Copepods, mysids and euphausiids, are important components of marine ecology, serving as linkages between phytoplankton and higher trophic levels (Bertness *et al. eds.* 2001; Johnson and Snook 1955). The migration activity of numerous crustaceans indicate that they are also active predators, feeding on small benthic and pelagic organisms such as diatoms, polychaetes, annelids, copepods, amphipods, euphausiids, mysids, and other crustaceans (Boutillier and Nguyen 1999). Larger crustaceans are typically opportunistic foragers fulfilling integral roles in marine ecosystems. Crustaceans extract from ecosystems, yet they often consume only a portion of their prey, leaving remains of their prey for other benthic scavenging organisms (Bertness *et al. eds*. 2001). Digging prey or some other predatory action by predators, can cause incidental mortality to other non-prey organisms, contributing to spatial patchiness within communities (Bertness *et al. eds*. 2001). As seen with some polychaetes, some crustaceans have the ability to regenerate limbs consumed by predators, likely contributing to their success (McLachlan and Ayres 1979). Crustaceans are prey to various predators at different ages and life cycle stages. Predators include marine mammals, birds, most fish species, cephalopods, crustaceans and other invertebrates. Juvenile Tanner crabs (*Chionoecetes tanneri*) are frequently and consistently found in fish stomachs, and it would appear that this species occupies a keystone role in the benthic food chain on the continental slope. Early Tanner crab instars redistribute nutrients from the bottom sediments to the demersal fish community in the water column (Gillespie *et al.* 2004b). The potential for over fishing of these crustacean predators may result in an increase crustacean prey populations while conversely, the over fishing of commercial crustacean prey species has the potential to play a limiting role in crustacean predator abundance.

In terms of reproduction, only a few commercial crustacean species have been studied in BC. For example, the pandalid shrimp found in PNCIMA protandric hermaphrodism, starting as males and then becoming females in the final year or two of their lives (DFO 1999g). Spawning typically takes place in late autumn to early winter with females brooding their eggs adhered to their abdomen throughout the winter (DFO 1999g). Certain species have planktonic larvae with limited mobility and remain pelagic for approximately three months while other arthropods have little to no pelagic larval stage. Species with pelagic larval stages, are frequently encountered in channels and near estuaries, and may show sensitivities to habitat alterations such as debris from coastal log storage and effluent discharge (Conlan and Ellis 1979; Booth 2000; Waldichuk 1979). Sessile crustaceans such as barnacles are highly successful colonizers as a result of their early maturity and ability to produce close to a million embryos per adult per season (Johnson and Snook 1955; Lamb and Hanby 2005).

British Columbian shrimp are susceptible to numerous parasites and diseases such as parasitic isopods and viral infections (Dunham and Boutillier 2001). Another parasitic barnacle, the black clawed crab parasitic barnacle (*Loxothylacus panopaei*) infects crabs. There are similar other parasitic barnacle species that infect hermit crabs and sea stars, but they have not been studied in any detail (Lamb and Hanby 2005). Parasitic isopods infest the bodies of larger crustaceans, forming relatively large bulges on the sides of shrimp, crab and fishes (Johnson and Snook 1955; Lamb and Hanby 2005). Often leaving their host, parasitic isopods may actively swim and search out a replacement host, leaving their former host with scars as evidence of parasitic attack (Lamb and Hanby 2005). Stained Prawn Disease (SPD), a rickettsia-like infection, is a parasite that has been detected in British Columbia waters, specifically in prawns located in Howe Sound and the Strait of Georgia. No cases have been reported within the PNCIMA region, and no causative agent has been determined (Bower *et al.* 1996).

Popularly called sea lice and whale lice, some arthropod parasites are strangely modified in structure according to their distinctive habit (Johnson and Snook 1955; Ricketts *et al.* 1968). Sea lice are parasitic copepods found on the skin, fins, gills and buccal cavity of marine fishes and all have variable success according to seawater surface salinity and temperature (Jones and Nemec 2003). Parasitic amphipods (*Cyamus* spp.), or whale lice, as well as free-living barnacles, parasitize grey whales and humpback whales (Ellis 1980). Some shrimp species harbour larval stages of parasitic worms (Austin 1985; Butler 1980; Lamb and Hanby 2005).

Commensal relationships involving arthropods are fairly common. One amphipod (*Orchomene recondita*) lives in the digestive system of sea anemones while others (*Hyperia*) hitch rides on various jellyfish (Lamb and Hanby 2005). Shrimp species are commonly found in boot and cloud sponges, while juveniles may seek shelter beneath urchin spines (Lamb and Hanby 2005). In an extraordinary relationship, box crabs (*Lopolithodes foraminatus*) and red king crabs (*Paralithodes camtschatica*) appear to harbour developing eggs of black-tail liparid, or snail fish, in their gill cavities (Hart 1982). Commensal relationships among non-commercial crab species found in PNCIMA have been reviewed by Hart (1982). Of particular note, the pea crab (*Pinnixia faba*) inhabits the cavity of the varnish clam which has caused some processing and marketing problems for the varnish clam (Gillespie *et al.* 2001).

9.2 Status & Management

There are over 87 species of shrimp present in BC waters and only seven are commercially-harvested in the shrimp trap and trawl industry. In PNCIMA, shrimp and prawn fisheries primarily take place in only a few North Coast inlets and offshore areas of the central coast. Shrimp stocks in BC have been assessed off the west coast of Vancouver Island since 1972 (Martell *et al.* 2000). For the nearshore shrimp stocks, index sites were established in 1997 along the coast and range from Chatham Sound in the north to the southern end of Vancouver Island in the Strait of Georgia. These nearshore index sites have a mix of annual and biannual fishery independent surveys. The primary objective of the surveys is to index shrimp biomass (Rutherford *et al.* 2004). The shrimp trawl fishery is managed using a fixed harvest rate based on the shrimp biomass determined from the fishery independent surveys. The commercial prawn fishery is managed using a female spawner escapement index. The fishery is closely monitored and monthly index reference points are established to ensure female spawning stocks are protected. The timing of egg hatch varies by area, and it is critical to understand when egg hatch is complete to allow for an opening of the fishery that protects breeding females sufficiently to allow for successful larval release. In most areas prawn stocks are considered healthy but fully exploited (DFO 1999f). In 1998, PNCIMA accounted for over 25% of the total coastwide commercial prawn catch (DFO 1999f).

There are five crab species fished in BC, Dungeness crab being the most significantly harvested. North coast Dungeness crab stocks are managed as two populations interacting to some extent. In PNCIMA, the Skeena River estuary and Hecate Strait/McIntyre Bay are two of six major Dungeness fishing areas (Fisheries and Oceans Canada 2002c). Typically, crab fisheries are managed by size and sex restrictions, in addition to some areas by season and gear restrictions (DFO 2000a). Experimental fisheries are licensed on large deeper-water species (Tanner crabs) to evaluate potential fisheries, since they have been sporadically fished in PNCIMA in the past. Additional crab species and their stocks are not currently assessed in BC and little published information is available, since they are not extensively commercially fished. Crabs are sensitive to pollutants such as pulp mill effluent and have been suggested as candidate species for monitoring marine ecosystem health (Yunker and Cretney 1995).

Since the 1970s, goose barnacles (*Pollicipes polymerus*) have been the only barnacle species commercially harvested in BC. Goose barnacles have long been a traditional food source for First Nations (Arima 1983; Ellis and Wilson 1981; Ellis and Swan 1981). In the early stages of the previous commercial fishery, there was limited harvesting in PNCIMA. However, due to logistics, the fishery continued only outside PNCIMA. Overall stock status of goose barnacles is unknown as there are very limited data available from assessments. However, they are abundant in selected but limited habitats of the rocky exposed open coast. The impact of harvesting is not fully understood and the fishery temporarily closed due to conservation and environmental concerns, and re-opened under scientific license in areas outside PNCIMA (DFO 1999a; Fisheries and Oceans Canada 2002b).

Since 1994, research into the euphausiid fishery has included acoustic surveys to assess biomass. This fishery takes place only outside PNCIMA with no intention to expand the fishery into new areas or increase the set 500 ton total allowable catch (TAC)(Fisheries and Oceans Canada 2003).

Another issue in PNCIMA includes controlling pathways that would cause spread of parasites and diseases. One parasite in particular, the shrimp parasitic barnacle (*Sylon hippolyte*) infects the spot prawn (*Pandalus platyceros*) in northern BC waters in PNCIMA, but not in southern BC waters. Therefore management action is required to contain this significant parasite and restrict movement of live prawns from these areas (Bower and Boutillier 1988).

9.3 Information Gaps, Uncertainties, Limitations & Variability

Although sightings have not yet occurred in the PNCIMA region, there is some concern over the anticipated arrival of the exotic/introduced European green crab (*Carcinus maenas*). Green crabs feed upon juvenile crabs of other species, including Dungeness and red rock crabs, and may compete for food sources. At the moment, Brooks Peninsula appears to be acting as a natural barrier to pelagic larvae, but since these organisms are quite mobile, European green crabs remain a potential threat to the PNCIMA region. The ecosystem impacts caused by a significant green crab population are presently unknown.

In total, there are close to 45 invasive arthropods in British Columbia waters, but their presence in PNCIMA are unknown (Carlton 1979).

To date, some arthropod groups have not been reported from northern latitudes but since there has been inadequate sediment and deep-water studies in BC, it would be unfair to assume that additional species do not occur in PNCIMA (Austin 1985). Future studies on monitoring parasites and other isolated diseases in invertebrates may be one mechanism to detect possible changes in the ecosystem and in marine environmental quality.

10.0 SUB-PHYLUM: UROCHORDATA

10.1 Biology, Habitat & Ecosystem Linkages

Commonly known as ascidians, tunicates or sea squirts, there are three classes of urochordates, two adapted for planktonic existence and a third forming living benthic habitat structures. In the Pacific Northwest, there are 82 ascidians documented of the approximate 3000 species worldwide (Austin 1985; Ruppert and Barnes 1994; Lambert *et al.* 2001). Although there are 14 planktonic species reported from the cold temperate NE Pacific, their occurrence is rare north of southern California (Austin 1985).

Few urochordates are solitary, while the majority are colonial. Colonies are made up of a few to hundreds of individual zooids, which may function independently or become integrated into an organized system (Ruppert and Barnes 1994). The majority of species are found in shallow coastal waters attached to the sides and under-surfaces of rigid substrates such as rocks, shells, pilings, ship bottoms, logs and seaweeds (Johnson and Snook 1955). Deeper-water species (up to 200 m) exist and, due to available habitat, are typically fixed in mud or sand by stalks or "roots" (Ruppert and Barnes 1994). Ascidians may be found in large clusters (*i.e.*, on gorgonian corals) or form large colonies that can reach several centimetres in thickness (Ruppert and Barnes 1994). Like many benthic invertebrates, sessile ascidians compete with sponges, sea anemones, corals, hydroids and bryozoans for substratum and when successful, may occupy substantial space (Bertness *et al. eds*. 2001; Smith and Carlton 1975; Ricketts *et al.* 1968).

Structurally, ascidians have two openings or siphons, and a body covering (tunic) or muscle bands in their body wall that provides structural support (Ruppert and Barnes 1994; Blake *et al.* 1996). Their siphons, one for in-current and the other for out-current, pass a significant amount of water through the body (up to 173 litres of water per 24 hours), and are used for filter feeding, gas exchange and mobility by a form of "jet propulsion" (Ruppert and Barnes 1994; Johnson and Snook 1955; Blake *et al.* 1996). Tunicates are highly successful planktonic grazers and are adaptable to unpredictable fluctuations in phytoplankton abundance, as they ingest a wide range of size and type of particles (Alldredge and Madin 1982). These traits have paved the way for rapid, exponential population increases when food supply is at a high. During periods of low food supply, they can survive without reproducing (Alldredge and Madin 1982). For some, reproduction can occur year round, but the majority breed during the summer months and reach sexual maturity in only a few weeks (Lambert *et al.* 2001; Ricketts *et* *al.* 1968; Blake *et al.* 1996). Both asexual (budding) and sexual reproduction takes place. Most colonies cross-fertilize for greater success through broadcast spawning (Ruppert and Barnes 1994; Blake *et al.* 1996). Although during their larval stage individuals have distinguishing chordate characteristics, these degenerate as adults making them an important invertebrate to NE Pacific ecosystems (Ruppert and Barnes 1994; Blake *et al.* 1996). The typical life span for ascidians range from 1 to 3 years, but some colonies have been known to live longer (Ruppert and Barnes 1994).

Ascidians host pea crabs, clams, amphipods and copepods, although the later can be a parasitic relationship (Ricketts *et al.* 1968; Bertness *et al. eds*. 2001; Blake *et al.* 1996). Although the tunic on ascidians acts as a physical and/or chemical deterrent, predation by flatworms, echinoderms, molluscs and three species of salmon (pink, chum and sockeye) on solitary and colonial forms occurs (Landingham *et al.* 1998; Blake *et al.* 1996).

10.2 Status & Management

Currently there are six invasive tunicates in BC, although none are yet known to exist in PNCIMA. Invasive tunicates have the potential to smother and overgrow other organisms and substrates, out-compete established species for food, as well as predate other benthic species larvae (Lambert *et al.* 2001). Many introduced species are associated with shipping and vessel traffic and, since there is significant vessel traffic in PNCIMA, the threat from the presence of invasive ascidians should be considered a significant issue. Risk assessments are currently being undertaken in the south coast region on four invasive ascidians occurring in BC waters.

10.3 Information Gaps, Uncertainties, Limitations & Variability

In PNCIMA, both deep-water and interstitial habitats have not been adequately investigated, as some un-described species have yet to be defined while others await their collection (Austin 1985; Blake and Scott 1997a). The presence of invasive species has only begun to be assessed in the south coast and considering some species ability to rapidly disperse, they may already have a strong presence in PNCIMA or have the potential to pose as a significant threat in the near future.

11.0 CONCLUSIONS

Throughout this chapter, a common theme has emerged from the information gaps identified for each phylum or group of invertebrates, and that is the lack of information on non-harvested invertebrate species. Some urchins, sea mussels (*Mytilus californianus*), and juvenile Tanner crabs (*Chionoecetes tanneri*) have been identified as keystone species, playing a critical role in the structure and composition of natural communities. The keystone role was determined only after investigations on the harvesting potential of particular species. What is not known is how many other invertebrate species have either keystone roles or other major functions in the overall marine environment. There is very little known on what marine invertebrates exist in PNCIMA, where they are located, and what roles they play in the marine ecosystem. There is awareness that marine invertebrates play an essential role in energy flow due to their relative positions in the food web. However, the extent and mechanisms of energy flow through marine ecosystems is not well understood.

In order to assess, plan and manage the impacts of human activities on the marine environment, building blocks are needed for a structured approach in understanding the complexities of the marine ecosystem. The basic steps to this structured approach would include:

1. An inventory of distinct marine communities.
2. The location, size and extent of those communities.
3. An understanding of the role and cumulative effects of those communities to the overall functioning and productivity of the marine ecosystem.
4. An understanding of the vulnerability and sensitivity of marine communities to human activities and other potential perturbations.

The marine invertebrates have a major role in the energy pathways of the marine environment. There are many knowledge gaps in the taxonomy, distribution, and abundance of marine invertebrates, with a subsequent lack of understanding on how many of the ecosystem processes function. These limitations need to be addressed in order to make informed management decisions.

12.0 GLOSSARY

Asexual budding – Offspring are produced by growing out of the body of the parent and is genetically identical to the parent.

Calcareous – Hard covering containing calcium carbonate.

Chitinous exoskeleton – A tough, protective, semitransparent substance, primarily a nitrogen-containing polysaccharide (chitin), forming the principal component of arthropod exoskeletons (the outer layer which serves not only as a protective covering over the body but also as a surface for muscle attachment, a water-tight barrier against desiccation and a sensory interface with the environment).

Climax community – The stage in community succession where the community has become relatively stable through successful adjustment to its environment.

Commensal relationships – The relationship between two kinds of organisms in which one obtains food or other benefits from the other without damaging or benefiting it.

Copulation – Mating.

Demersal – Organisms located at or just above the sea floor.

Dioecious – To have separate sexes.

Epifauna – Organisms living on the seabed surface.

Estuary – An inlet or arm of the sea; especially the wide mouth of a river, where the tide meets the current.

Gametes – Reproductive cells; sperm and egg cells in animals.

Gorgonian – Corals having a horny calcareous branching skeleton.

Keystone species – A species that has a key role in an ecosystem, affecting many other species, and whose removal leads to a series of extinctions within the ecosystem.

Megafauna – Large plants.

Metamorphosis – A change in body form.

Mutualistic – An interaction between two species in which both species benefit.

Ossicles – The numerous small plates that constitute the echinoderm skeleton. Ossicles are composed of a form of calcium carbonate known as calcite.

Phylum – A major group within a kingdom. Members of a phylum share a common structure and organization.

Planktonic – Drifting small organisms that inhabit the water column of the ocean.

Protandric hermaphrodism – Undergo a change of sex in mid-life.

Rickettsia-like infection – A parasitic micro-ogranism, intermediate between bacteria and viruses associated with infection.

Sedentary – Remaining or living in one area, not moving freely.

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2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX G: GROUNDFISH

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1.0 INTRODUCTION

Groundfish are fish species that spend most of their time on or near the sea bottom. They can be divided into four general groups with similar characteristics: roundfish, flatfish, rockfish and elasmobranchs. Many are habitat/site specific and the juveniles often occupy a different niche than the adults. They display a considerable amount of phenotypic plasticity with regard to reproduction. Some species spawn in late winter or early spring with eggs released and fertilized in the water column, others are batch spawners and have protracted spawning periods. Reproductive strategies vary among species as well. Some species maximize fecundity, while others maximize survival of their offspring with parental care. Elasmobranchs give birth to live young that are sustained by a yolk sac in the days following spawning, while rockfish undergo internal fertilization and release live larvae. They are all iteroparous – spawning many times during their lifetime likely because of the uncertainty of their oceanic environment. Individual life history characteristics determine how species will respond to exploitation and environmental perturbation. Flatfish species with their moderate growth and natural mortality rates are the most robust to over fishing whereas rockfish species, particularly the long lived species, are the least robust.

Groundfish species are harvested year round by trawl, longline, and trap, and form the most significant fishery in British Columbia (BC) in terms of landed catch weight. In recent years they have been increasingly targeted by the recreational sector, especially in the Strait of Georgia. The commercial fisheries catch a wide range of species that can be categorized in two ways: 1) species of commercial value that are retained for sale, and 2) species with no commercial value which are released at sea. In recent years the industry has significantly reduced the proportion of species in the latter category. Groundfish fishery managers rely on stock assessment advice provided by the Science Branch of Fisheries & Oceans Canada (DFO) to set TACs (Total Allowable Catch) for species caught in commercial fisheries. Data collection encompasses all species caught in all areas of the coast. Research and commercial fishery data are housed in two modern relational databases. Analysis of species abundance and distribution data incorporates both spatial and temporal features. Recent surveys have employed the use of visual methods to examine species density in relation to habitat type. This type of data remains limited for most species but is critical to understanding the role of habitat in marine ecosystems.

2.0 LIFE HISTORY

2.1 Roundfish

Roundfish species exhibit two general life history patterns: 1) opportunistic life strategy employed by forage fish and 2) intermediate strategy exhibited by larger, more long lived species. Forage fish species are discussed in Appendix H: Pelagic Fishes, and will not be discussed here. Intermediate strategists, including lingcod, true cod, tuna, mackerel and hake exhibit life history traits that are intermediate between short-lived small forage fish with high growth rates, and long lived, slower growing rockfish species. For example, fish species in the intermediate category are typically larger and live longer than forage fish. Most do not live as long as rockfish and they may have large migratory ranges. Prey species for this group include euphausiids and fish.

2.2 Rockfish

Rockfish are generally long lived and slow growing; with maximum ages of over 100 years and age of maturity ranging between 5 and 20 years. They exhibit high fecundity, and have some parental investment. Most rockfish undergo internal fertilization and release live larvae in late winter or early spring. Rockfish are primarily piscivores. They have a pelagic larval or juvenile stage and adults inhabit ranges within subtidal, shelf, or slope benthic habitats. Rockfish have periodic high recruitment events, associated with favourable environmental conditions (King and McFarlane 2003). Compared with roundfish species, the abundance of rockfish populations fluctuate less frequently. Their longevity ensures more years of production per individual and provides insurance against unfavourable environmental conditions. Strong year classes occur on average about once a decade. Rockfish species including Pacific ocean perch, yellowmouth rockfish, silvergray rockfish, canary rockfish, and redstripe rockfish are very important to the commercial fishery. However, managing the commercial harvesting of rockfish is difficult, as long lived species are the least robust to fishing, and require an extremely long rebuilding period after depletion (several decades).

2.3 Flatfish

Flatfish, including halibut, and sole and flounder species, are also periodic strategists but show some differences in life strategy compared to rockfish (King and McFarlane 2003). Flatfish exhibit high fecundity and show little parental investment. Maximum age ranges between 20 and 45 years, and most mature between 3 and 5 years. Flatfish species have a relatively high intrinsic rate of increase and high reproductive output compared to most species. Thus they are more robust to fishing than most other groundfish species.

2.4 Elasmobranchs

Elasmobranchs are long lived, large in size and have delayed maturation. They are slow growing, have low fecundity, and in some cases long gestation periods (King and McFarlane 2003). They exhibit a high degree of parental investment, usually giving birth to live young that are sustained by a yolk sac in the days following spawning. Elasmobranchs include skate and shark species, and are high-order carnivores and piscivores inhabiting a wide range of habitat. Individuals of some species such as dogfish have been found to migrate large distances (McFarlane and King 2002), while others have a high degree of endemism. Elasmobranchs have a low intrinsic rate of increase that may require long periods for rebuilding due to their low reproductive output.

3.0 FISHERY

Groundfish fisheries target on both demersal and pelagic fish species caught on offshore fishing 'grounds'. Commercial species encompass all of the previously mentioned species groups. In addition, the catch includes non commercial species such as poachers, sculpins, gunnels, and eelpouts. There are three general gear types: trawl (all species), longline (rockfish and halibut), and trap (sablefish). The groundfish fishery has increased greatly in value over the last twenty years and provides employment for the fish processing industry all year.

The trawl fishery in BC began in the early 1900s (Wilderbuer *et al.* 2005), although trawling by Canadian vessels did not begin in earnest until after 1945. In the 1960s there were large removals by foreign vessels which operated on 'grounds' inside the 12 mile limit off the west coast until Canada declared extended jurisdiction in 1977. There were few regulations governing the fishery until DFO began to establish quotas and other catch limitation measures by species and areas in the late 1970s. Over time these measures have included license limitations, establishment of Total Allowable Catches (TACs), use of fishing area closures (time/area) and implementation of vessel trip limits for commercial species.

Since 1978, DFO managers have consulted with stakeholders prior to developing annual plans for the management of the groundfish fisheries. The current process includes all stakeholder groups in an atmosphere of co-management. In 1997 DFO and the groundfish trawl industry agreed on a plan to implement an Individual Vessel Quota (IVQ) system. The result was the most advanced fishery management system in the world (Branch *et al.* 2006). Transferable quotas were set for 25 different species in 55 different species area groups. Under this system fishermen have more flexibility to choose when, where, and how to fish. Discards at sea are also minimized and the IVQ system has resulted in full mortality accounting in the British Columbia groundfish fishery. Fishermen wanting additional quota for a given species can arrange to lease or buy quota from another holder.

Any marketable fish released at sea is deducted from the vessel's quota. In addition, since 1996, observers record comprehensive information on catch on every offshore trawl vessel while inshore vessels have electronic monitoring to validate their catch. This allows managers to accurately determine catch and bycatch levels, thereby strengthening their capability. The observer program provides comprehensive data from the fishery and valuable information on discards, locations of catch, time of catch, and species composition of the catch.

Overall, discard rates of marketable fish in the trawl fishery dropped from 25% in 1995 to 7% in 2005 (Branch *et al.* 2006). Prior to 1996 the amount of discards was unknown but some reports put it at more than double that in the IVQ inaugural year of 1996. The decrease in discards has been largely due to the IVQ fishery but also reflects the changing attitude of fishermen. The fishing industry is working to find markets for discarded species and is developing mitigation measures to reduce discards.

In 1999, DFO introduced at-sea observers in the halibut fishery and, in 2001, expanded this requirement to other groundfish longline fisheries. Bycatch in the longline industry has been a key issue with the advisory groups. Commercial sectors (Commercial Industry Caucus) are currently working toward an integrated groundfish industry. As of April 1, 2006, quotas were shared across gear types and one set of regulations and areas was used to manage the entire fishery. All vessels must retain observers or have electronic monitoring.

The current groundfish trawl fleet is composed of approximately 88 vessels landing approximately 140,000 tonnes annually, worth an estimated value of $60-65 million. Twenty five species make up 95% of the landings by weight (Figure G.0, Table G.0, Figure G.1, Table G.1), with 77 species landed. To date 27 different groundfish stocks have been assessed and subject to annual allocations in eight different management areas.

As mentioned before, in addition to the trawl fleet, the Department also regulates the sablefish fleet, the ZN (rockfish) fleet and the halibut fleet. However, quotas for the halibut fleet are set by the International Pacific Halibut Commission. Locations and catch in the non-trawl groundfish fisheries are illustrated in Figure G.2, Table G.2, Figure G.3, and Table G.3.

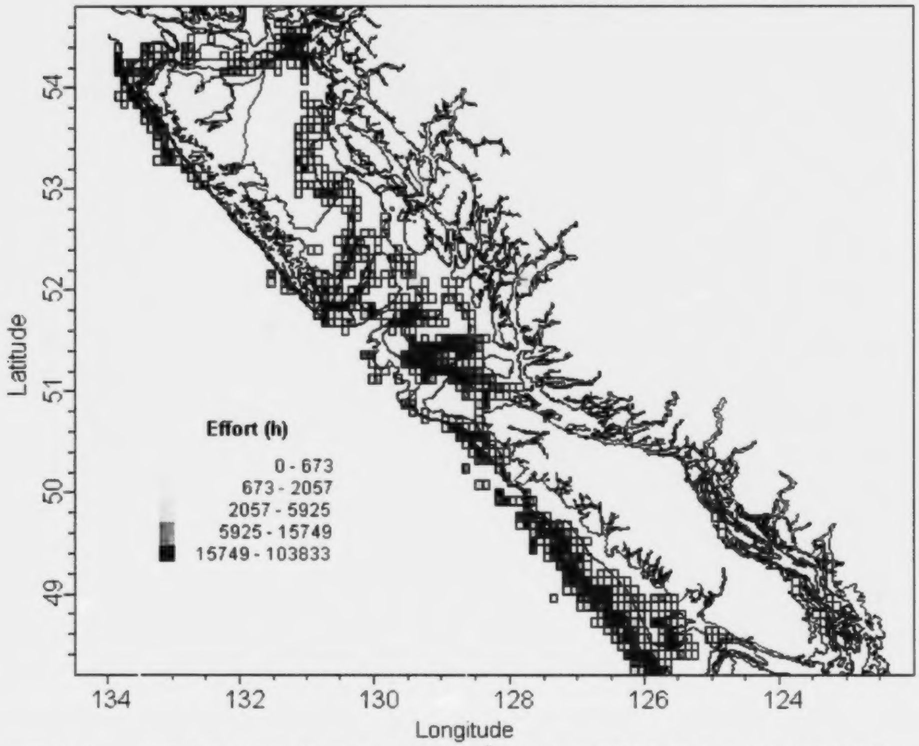


Figure G.0 Total fishing effort (hours year^{-1}) for the British Columbia trawl fishery in 2005.

The hook and line groundfish fishery involves the use of longline, troll, and hand line to catch rockfish, lingcod, dogfish, skate, Pacific cod, sole, and flounder. Rockfish are caught under the authority of trawl and ZN licenses while by catch of rockfish occurs in the salmon troll, halibut, dogfish, and sablefish (seamount only) fisheries (Yamanaka *et al.* 2004). The category ZN license was created in 1986. Prior to 1986, rockfish could be harvested commercially by hook and line gear by any vessel with a vessel-based license allowing the fisher to catch Schedule II – other species. In 1987, 1,935 ZN licenses were issued. The number of ZN licenses issued increased to a high of 2,395 in 1990. ZN licenses are not vessel-based licenses but personal licenses that must be designated to a fishing vessel each year upon license issuance.

Table G.0 Groundfish species that make up 95% of the landings from the British Columbia trawl fishery.

- **Rockfish**
  - Canary rockfish
  - Yelloweye rockfish
  - Redstripe rockfish
  - Sharpchin rockfish
  - Bocaccio
  - Widow rockfish
  - Silvergray rockfish
  - Redbanded rockfish
  - Pacific ocean perch
  - Shortspine thornyhead
  - Yellowmouth rockfish
- **Elasmobranchs**
  - Skates
  - Ratfish
  - Dogfish
- **Roundfish**
  - Sablefish
  - Lingcod
  - Pacific cod
  - Pacific hake
  - Walleye pollock
- **Flatfish**
  - Butter sole
  - Sand sole
  - Rock sole
  - English sole
  - Petrale sole
  - Flathead sole
  - Rex sole
  - Dover sole
  - Pacific halibut
  - Arrowtooth flounder

Table G.1 Species caught incidentally in the groundfish trawl fishery. These species make up the "Trace" category from Figure G.1.

Oreos
Dragonfish and viperfish
Bristlemouth and fangjaw
Lumpsuckers and skilfish
Slipskins
Pacific sandfish
Hairtails
Medusafish
Pricklebacks
Pacific barracuda
White croaker
Quillfish
Gunnels
Gobies
Giant wrymouth
Manefishes
Pomfrets
Northern ronquil
Tubeshoulders
Barreleye
Javelin spookfish
Myctophids
Dreamers
Opah
Clingfishes
Pipefish and tubesnouts
Cuskpout
Crested ridgehead
Toadfishes
King-of-the-salmon
Billfishes

The Groundfish Hook and Line Advisory Committee (GHLAC) was established in 1990 to advise DFO about issues concerning the groundfish hook and line fisheries. This committee is comprised of representatives of fishers, processors, the United Fisherman and Allied Workers' Union (UFAWU), First Nations, and the Province of BC. Rockfish area licensing (inside/outside) was implemented in 1991 with 2,183 ZN licenses issued: 592 Inside (Strait of Georgia) and 1591 Outside (remainder of the coast). Limited entry was implemented in the inside fishery in 1992, resulting in 74 eligible licenses, and the outside fishery in 1993, resulting in 183 eligible licenses. Maximum vessel length restrictions were included with the limited entry program.

Management measures for rockfish have been increasingly restrictive to ensure resource conservation. Management measures currently in place for the inside and/or outside rockfish fisheries include: area TACs, trip or fishing period limits, incidental catch allowances, relinquishment of limit overages, area/time closures (including Rockfish Conservation Areas), option selection, seabird avoidance measures, at-sea monitoring, and 100% dockside monitoring.

The inside rockfish fishery in 2003/04 season had 65 active licenses. Unlimited stacking of licenses is permitted for the Strait of Georgia resulting in a total of 26 vessels fishing in the 2003/04 season. The TAC is split evenly between all the eligible licenses (74). Fishing season is open between April 1 and March 31 every year.

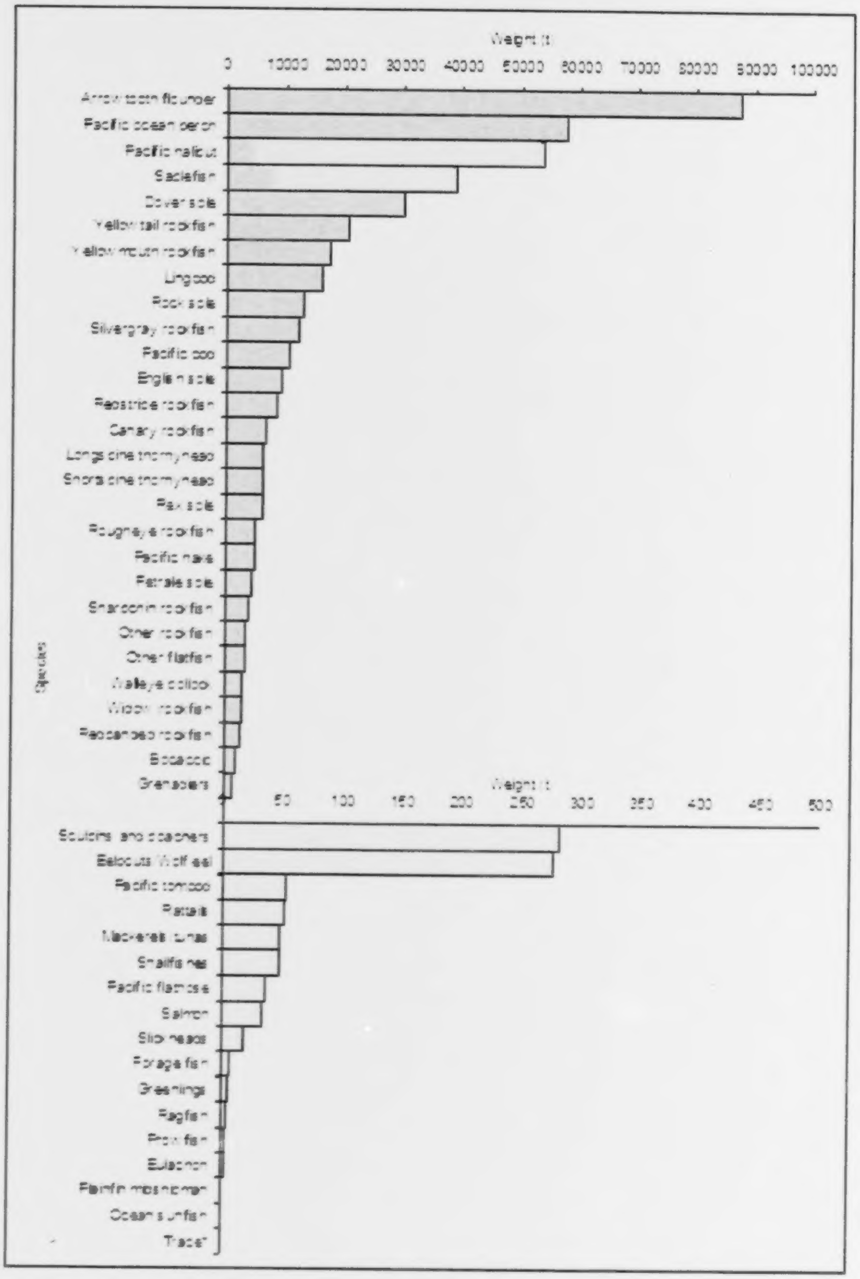


Figure G.1 Species catch by weight in the British Columbia trawl fishery from 1996 to 2005. Sablefish and halibut catch combines trawl (dark blue) and sablefish or halibut fishery (light blue) catches, respectively. Species included in the lower chart account for less than 1% of the cumulative catch by weight. Trace category includes catches of nearly 50 species.

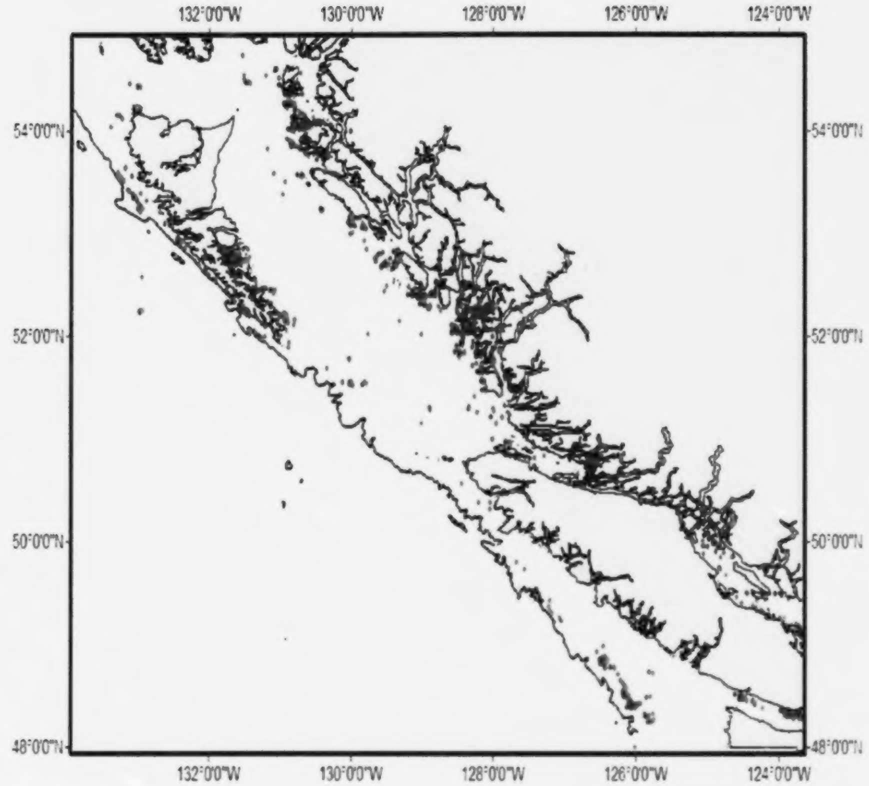

132°0'0"W
130°0'0"W
128°0'0"W
126°0'0"W
124°0'0"W
54°0'0"N
52°0'0"N
50°0'0"N
48°0'0"N

Figure G.2 Set locations for the British Columbia ZN (rockfish) and Schedule II (other species) fisheries in 2002.

Table G.2 Groundfish species caught in the hook and line fishery. Species listed comprise 95% of the landings.

- **Rockfish**
  - Rougheye rockfish
  - Yelloweye rockfish
  - Quillback rockfish
  - Redbanded rockfish
  - Silvergray rockfish
  - Shortraker rockfish
  - Copper rockfish
  - China rockfish
  - Canary rockfish
  - Yellowmouth rockfish
  - Black rockfish
  - Tiger rockfish
  - Bocaccio
  - Vermilion rockfish
  - Shortspine thornyhead
  - Yellowtail rockfish
  - Redstripe rockfish
  - Widow rockfish
  - Pacific ocean perch
  - Rosethorn rockfish
  - Greenstriped rockfish
  - Blue rockfish
  - Dusky rockfish
- **Elasmobranchs**
  - Spiny dogfish
  - Skates
- **Roundfish**
  - Pacific cod
  - Sablefish
  - Lingcod
  - Greenlings
- **Cottids**
  - Sculpins
  - Cabezon
- **Flatfish**
  - Pacific halibut
  - Rock sole
  - Arrowtooth flounder

The outside rockfish fishery is divided into several Options: Option A targets quillback, copper, china, and tiger rockfish for the live rockfish market; Option B is primarily a yelloweye rockfish fishery that delivers to a 'fresh' market; Option C lands primarily deep-water species such as shortraker rockfish, rougheye rockfish, and redbanded rockfish; and Option D is a combination fishing program for vessels licensed for both halibut and outside rockfish. Fishers must select their options prior to the season. Only one license is permitted per vessel. For 2004/05 fishing season, of the 191 eligible licenses, 43 chose Option A, 16 Option B, 21 Option C, and 111 Option D.

Inshore rockfish are caught in longline fisheries coastwide. Historically, the largest component of the catch has been taken by commercial fishers. However, catches from the recreational sector have increased significantly in recent years in the Strait of Georgia. Catch records from the commercial fishery are taken from logbook reporting, dockside monitoring, and onboard observer programs. Recreational fisheries are monitored in various locations on the coast through creel surveys and logbook programs.

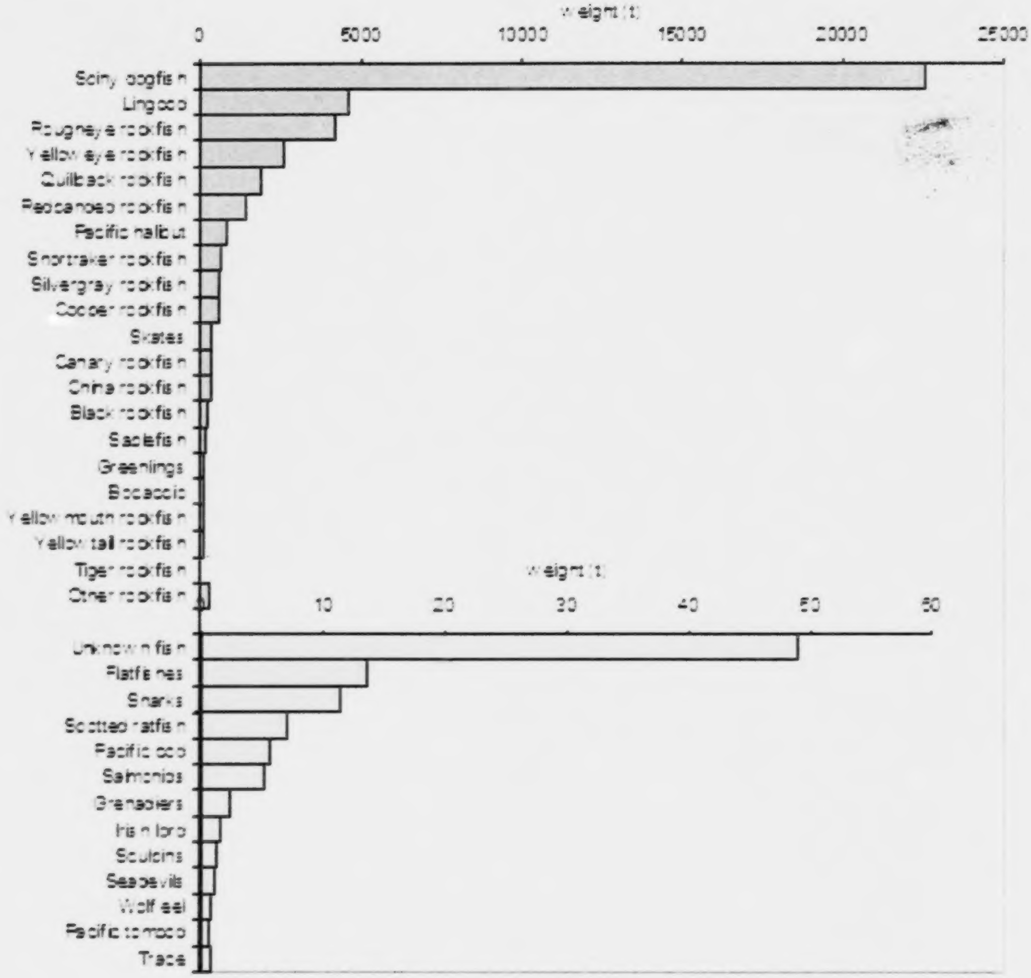


Figure G.3 Species catch by weight in the BC hook and line fishery, 1996 to 2005. Species included in the lower chart account for less than 1% of the cumulative catch by weight. Trace category includes small catches of 15 species.

Table G.3 Species caught incidentally in the groundfish hook and line fishery. These species make up the "Trace" category from Figure G.3.

Drums
Bigfin lanternfish
Pacific hake
Skilfish
Surfperches
Striped marlin
Prickleback
Tubenoses
Walleye pollock
Barracudinas
Snailfishes
Rockweed gunnel
Wrymouths
Sturgeons
Hagfishes

4.0 DATA SOURCES

Groundfish data collection began at ports of landing in the early 1950s. From 1954 to 1995 port samplers collected information from a voluntary logbook program. However, some fishermen did not participate in the logbook program and some withheld information. Historically, commercial fishery data was housed in a database, GFcatch, with individual records corresponding to spatial/temporal scales. Information was pooled by fishing ground and not resolved by individual haul. In the early 1990s, work commenced on two modern relational databases. The first, PacHarv, houses all commercial fishery data collected since 1996. The second, GFbio, contains all of the data that has been collected on research cruises over the last 50 years. These two databases provide the comprehensive information required for stock assessment and research work.

5.0 STOCK STATUS AND MONITORING

5.1 Research surveys

The need for research surveys arose because of the bias that exists in data collected from the commercial fishery. Fishermen do not sample the resource in a random fashion. Fishery CPUE (catch per unit effort) was a proxy for species abundance since the monitoring of fisheries began. Over time, regulatory effects and increasing vessel efficiency made these data less reliable. In response to this, scientists developed and implemented research surveys that meet the strict requirements for data analysis. A series of synoptic surveys were established starting in 2001 to provide CPUE data and biological data to meet the increasing demand for stock assessment, *Species At Risk Act* (SARA) mandate, and ecosystem work (Figure G.4).

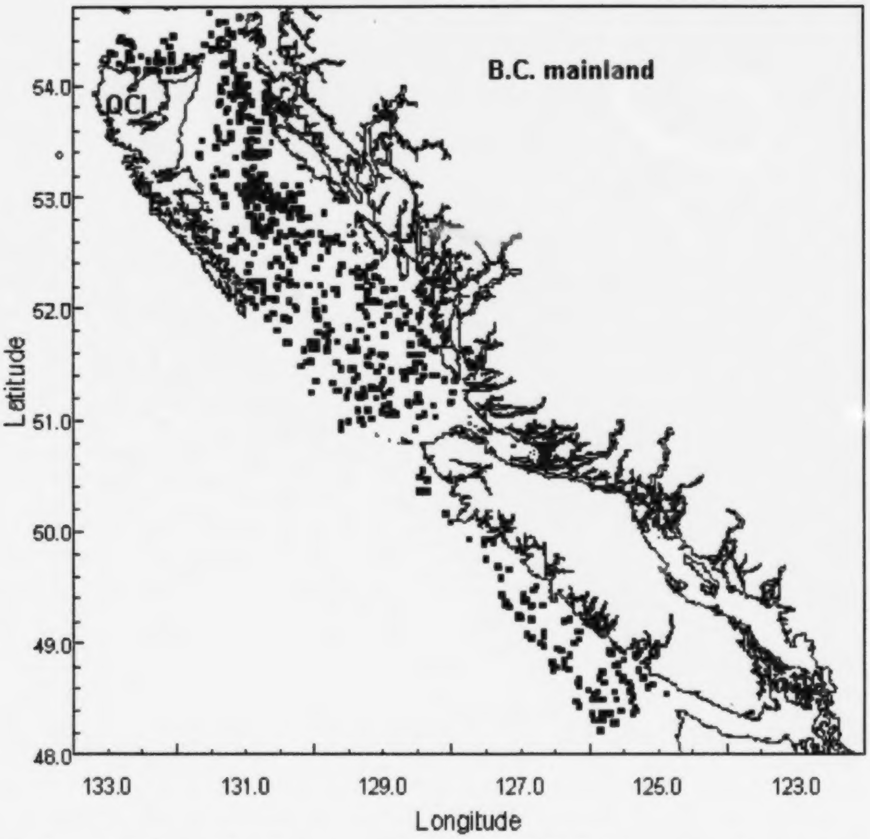


Figure G.4 Locations of stations occupied during DFO Science synoptic surveys, 2001 to 2005.

The distributions of individual species were categorized for potential relative indexing in stratified random surveys (Fargo and Tyler 1992). Type 1 species were characterised by consistent overall distribution and areas of peak density among years. Mean catch rates for these species were relatively similar in winter and in summer, with little seasonal difference in depth distribution, and little difference in depth distribution by size of individual. Type 1 species were therefore had stable distributions in space and time, making them appropriate candidates for abundance monitoring. Type 2 species were characterized by relatively consistent overall distribution, but variability in density. Mean catch rates and distribution of type 2 species varied by season. Type 3 species were characterized by a high degree of variability in density by season and year. These species exhibited schooling behaviour and, although they were present throughout the survey area, their overall distribution may vary widely in time and space. These species were the least suitable candidates for abundance monitoring. Species associations with depth, temperature, and bottom type have also been described (Figure G.5) accounting for seasonal and ontogenetic variability.

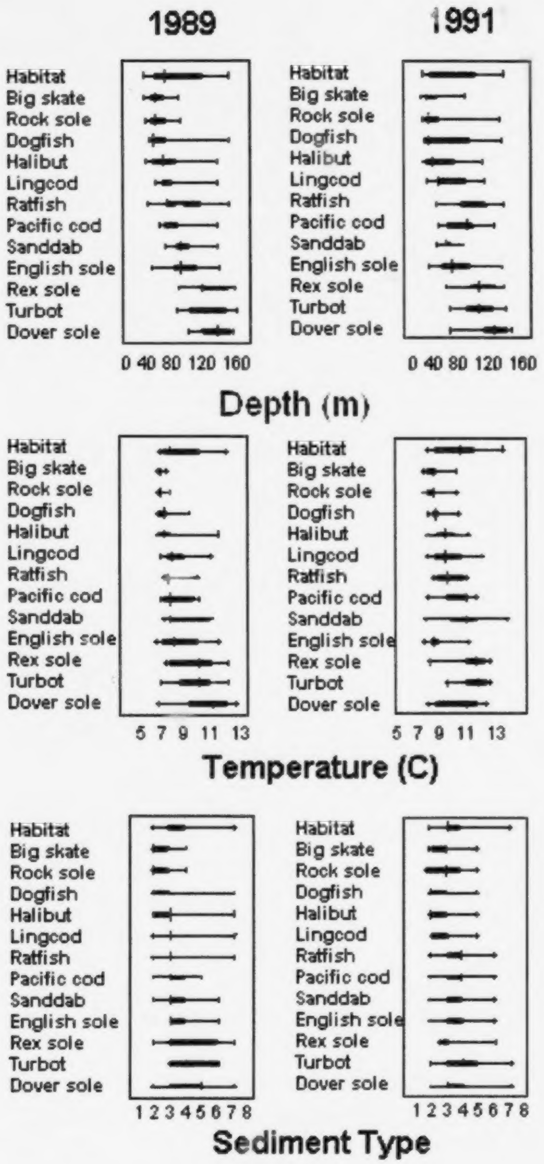


Figure G.5 Quartile plots of the distribution of available habitat and groundfish species as sampled May-June 1989 and 1991. Species such as Dover sole and big skate exhibited relatively narrow depth, temperature, and sediment type preferences, while species such as lingcod and dogfish had distributions that were not significantly different from random on depth, temperature, and sediment type. Sediment type categories are: 1) gravel, 2) very coarse sand, 3) coarse sand, 4) medium sand, 5) fine sand, 6) very fine sand, and 7) silt (figure reproduced from Perry *et al.* 1994).

5.2 Ecosystem/multispecies considerations

Several different approaches to ecosystem/multispecies work have been used by principal investigators over the last decade.

1. **Mass-balanced models.** These models are driven by trophically linked biomass 'pools' consisting of species groups or ecological guilds. Data requirements include: biomass estimates, total mortality estimates, consumption estimates, diet compositions, and fishery catches.
2. **Assessment and management by critical species**. Maintenance of the diversity of an entire assemblage may result from normal catch quota management of a group of species. The persistence of all species in the area during the conduct of a fishery is perceived as a legitimate goal here.
3. **Species interaction models**. Modelling of species interactions may provide estimates of joint-species yields or provide insight into particular management oriented questions.
4. **Management by trophically linked species or guilds**. Cohabiting, resident species with strong trophic linkages have properties of integrated productivity that are assessed to develop species-group quotas and may be conceptualized as production units.
5. **Total system yield estimates using particle size dynamics theory**. Evidence has accumulated that there is a relationship between animal body size and the sustainable number of animals of a particular size (Sheldon *et al.* 1982). This theory has been developed for pelagic species but not for demersal fish species.

Most recently, scientists have focused attention on ecosystem mass-balanced models. One study area on the Pacific coast has been Hecate Strait (Figure G.6; http://www-sci.pac.dfo-mpo.gc.ca/sa-hecate/). Existing data for that region includes 50 years of commercial fishery data, 20 years of multispecies survey data, physical and biological oceanographic data and habitat type. Areas of study in this project included phytoplankton/zooplankton productivity, ocean circulation, species abundance and distribution, species habitat association/utilization, and food resource division. Three distinct fish communities dominated by flatfish species were identified and characterized by bathymetry and habitat type (Figure G.7). Three types of species components were associated with each community: a) regular components were always associated with the community and had no seasonal or temporal variability in overall distribution, b) seasonal components were present in the community during summer or winter only due to migrations, and c) transient components had highly variable distributions and moved freely between communities.

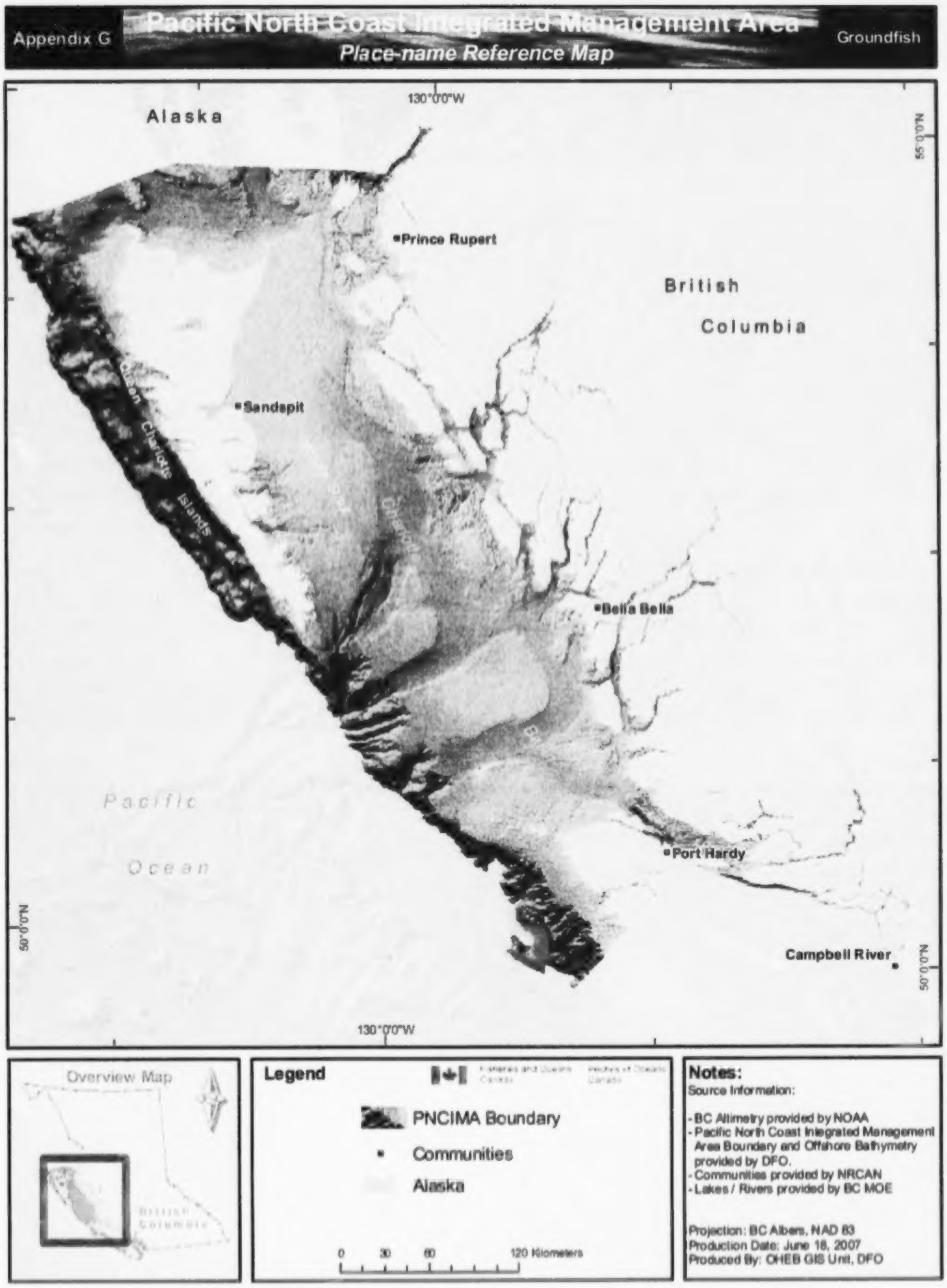

Appendix G
Pacific North Coast Integrated Management Area
Place-name Reference Map
Groundfish
130°0'0"W
Alaska
55°0'0"N
Prince Rupert
British Columbia
Sandspit
Queen Charlotte Islands
Bella Bella
Pacific Ocean
Port Hardy
Campbell River
50°0'0"N
130°0'0"W
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
Pêches et Océans Canada
PNCIMA Boundary
Communities
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure G.6 PNCIMA region showing locations and features of BC waters.

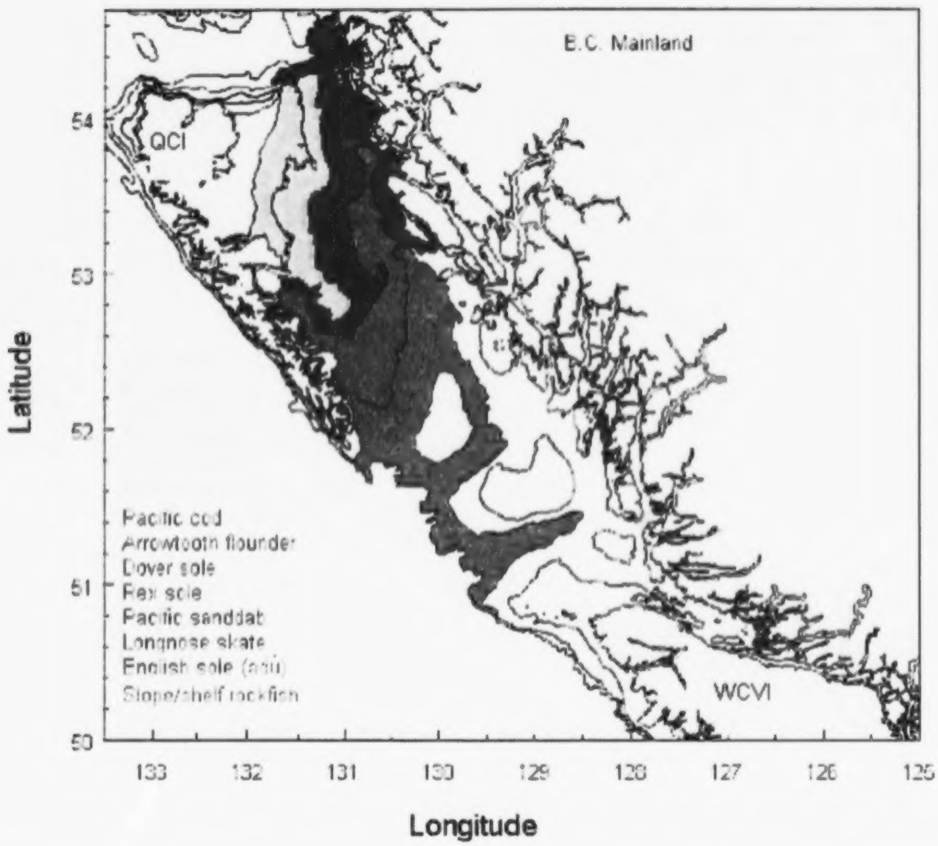

E.C. Mainland
QCI
WCVI
Pacific cod
Arrowtooth flounder
Dover sole
Rex sole
Pacific sanddab
Longnose skate
English sole (adu)
Slope/shelf rockfish
Latitude
54
53
52
51
50
133
132
131
130
129
128
127
126
125
Longitude

Figure G.7 Key components of fish communities in the Queen Charlotte Basin were characterized by bathymetric boundaries shown (light blue 0-50 m, dark blue 51-160 m and red >160 m, juv = juvenile, and adu = adult) and habitat type. Fish communities in white areas are less well known.

Pearsall and Fargo (Pearsall and Fargo 2007) determined that there were 5 main feeding strategies in Hecate Strait (outlined in Table G.4). Within a category, some species had widely variable diets, such as Pacific cod, arrowtooth flounder, and dogfish; while other species showed a high degree of dependence on a few prey items, such as the planktivore yellowtail rockfish. In general, the greatest diet breadth was found in piscivores, and the lowest diet breadth was found in planktivores and benthivores.

Similarities in diet preference were noted within groups; for example, many of the flatfish species had similar diets, as did the skate species. The 5 main feeding strategies were:

1) Fish feeders fed mainly on forage fish (herring and sandlance), flatfish, and shallow water benthic fish;
2) Shrimp feeders fed mainly on *Crangon* species and *Pandalus* species;
3) Crab feeders fed primarily on crabs, bivalves, and anomurans;
4) Annelid feeders fed primarily on annelids, with lesser amounts of echinoderms, echiurans, and cnidaria;
5) Plankton feeders showed the least varied diets, feeding primarily on euphausiids with a preference for *Thysanoessa spinifera*, except for eulachons and yellowtail rockfish for which *Euphausiida pacifica* was most important.

Table G.4 Feeding strategies for some marine fish species in Hecate Strait.

Plankton feeders
Pacific ocean perch (adult and juvenile)
Eulachon
Yellowtail rockfish
Sablefish
Pacific sanddab

Annelid feeders
Dover sole (adult and juvenile)
English sole (adult and juvenile)
Rex sole
Rock sole (adult)

Crab feeders
Big skate
Longnose skate
Redbanded rockfish
Ratfish

Shrimp feeders
Walleye pollock
Speckled sanddab
Flathead sole
Black skate

Fish feeders
Arrowtooth flounder (adult and juvenile)
Petrale sole
Dogfish
Pacific cod (adult and juvenile)
Sand sole
Silvergray rockfish
Flathead sole
Black skate

Seasonal and spatial diet patterns were discerned for some groundfish species, with seasonal differences being more common than spatial differences. Species demonstrating seasonal variation included a greater volume of fish in their diet in the fall and winter than in the summer. Annelid and crab feeders generally showed less spatial and temporal variability than fish feeders. Fish feeders generally demonstrated a greater degree of ontogenetic variability than species with other prey strategies.

Although the term 'food chain' has entered into common usage, in most ecosystems food chains do not exist. Trophic interactions are considerably more complex than a series of linear steps (Figure G.8). Trophic levels identify the kind of food an organism uses. The total number of trophic levels depends upon the location and number of different species in the ecosystem. The highest trophic level is occupied by adult animals with no predators of their own. For example, killer whales (Orcas) occupy the highest trophic level in BC waters. Most organisms have more than one predator and the diet of most animals shifts as they develop. An example of this shift is Pacific cod and English sole adults occupying a higher trophic level than juveniles (Figure G.8). The presence of two or more competitors feeding on the same prey items may alter the availability of energy to higher trophic levels.

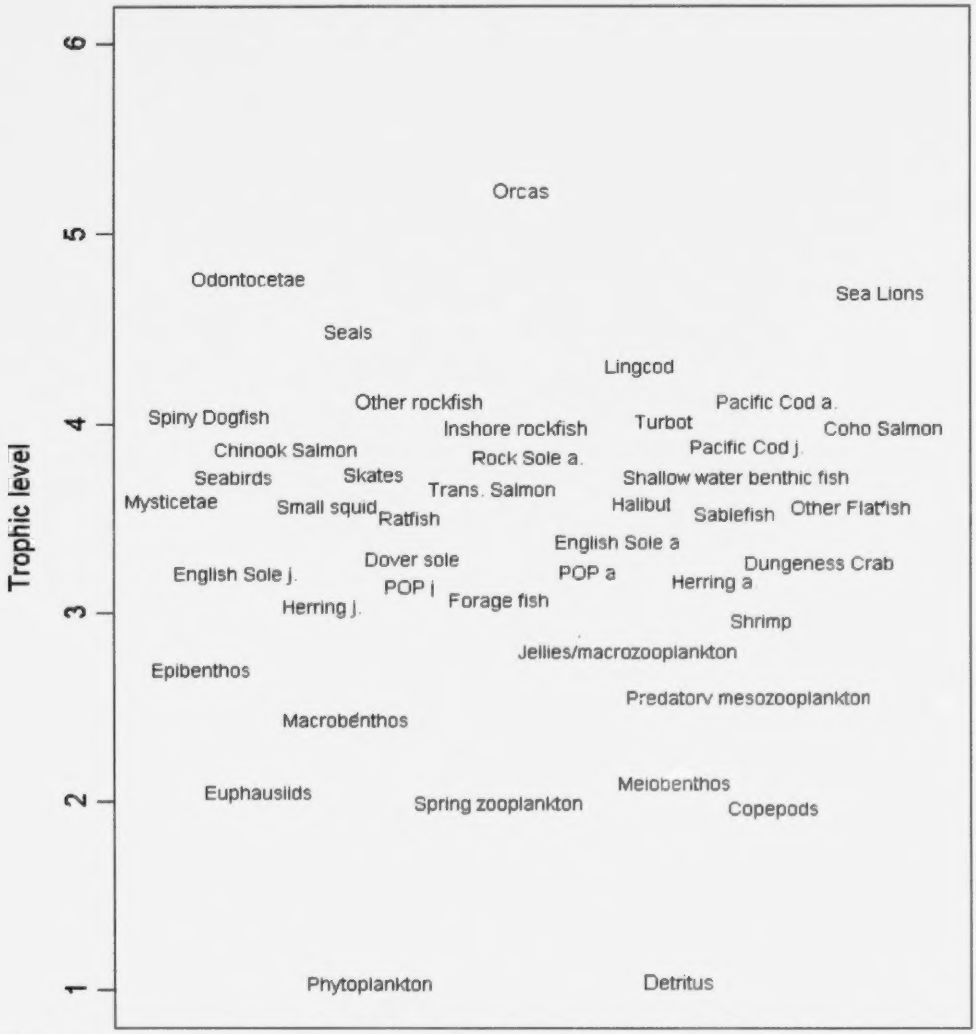


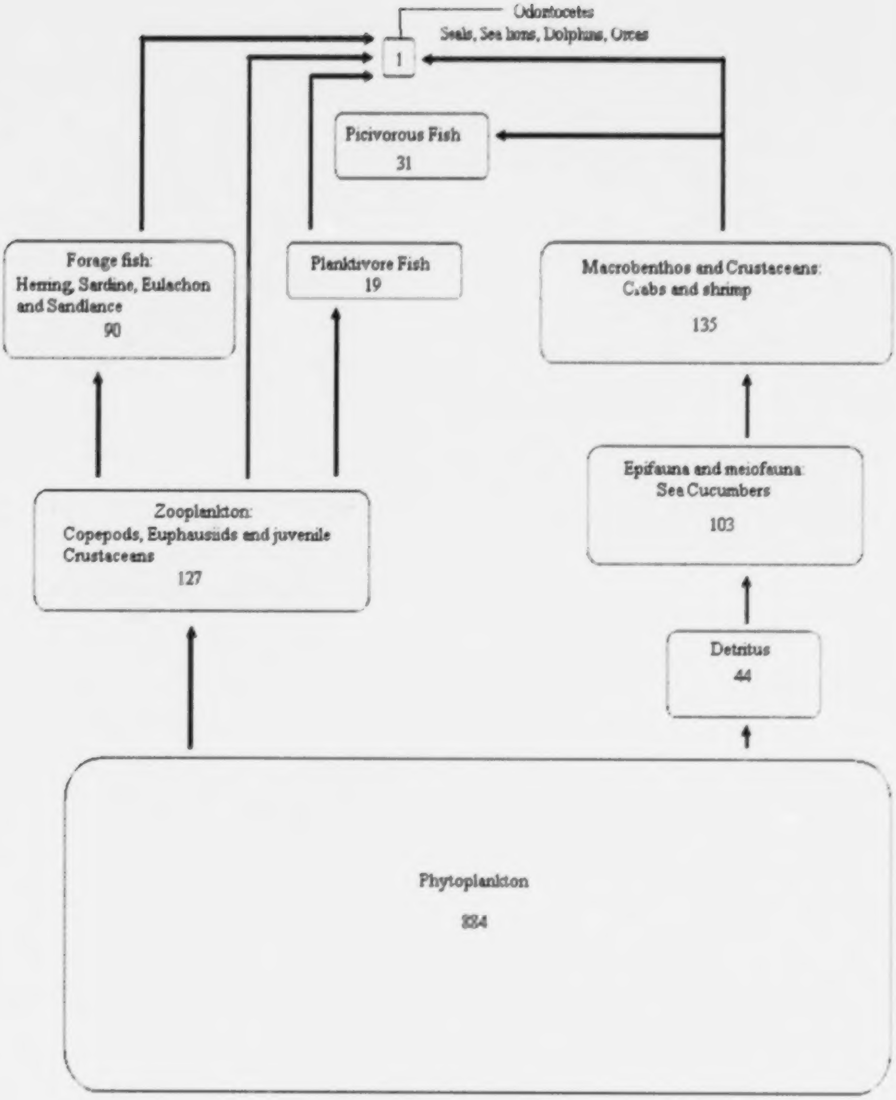
Figure G.8 Output from Ecopath/Ecosim illustrating trophic levels in the Queen Charlotte Basin. Note that groundfish species occupy more than one trophic level. For example, Pacific ocean perch (POP) is a planktivore (level 2-3), English sole feeds primarily on annelids (level 3-4), and Pacific cod and lingcod are piscivores (level 4). Adults of a species are indicated with the addition of the letter a, juveniles by j, transients by trans.

The flow of nutrients in a food web is cyclical. A pool of nutrients resides in a trophic level until animals die, excrete waste, are eaten, or are removed in fisheries. During primary production, inorganic nutrients are incorporated into cells during photosynthesis and chemosynthesis. Energy is captured by primary producers and transferred to higher trophic levels. At each transfer, only a fraction of the energy is passed on and much is lost. Total available energy declines at each trophic level. This places a limit on the number of trophic levels that can exist. At some point, there is too little energy available to sustain further transfers. Typical transfer efficiency from primary producers to planktivores is about 20%, while efficiencies between higher levels are about 10%. Secondary production refers to the total amount of animal biomass produced in all trophic levels above the primary producers.

Using an Ecopath/Ecosim model (Christensen and Pauly 1992), 6 trophic levels were determined from groundfish diet data (Figure G.8). Using this information, we were able to produce a simplified food web depicting species interaction and energy transfer between the trophic levels. Figure G.9 illustrates the energy flow for the marine community in the Queen Charlotte Basin. It consists of species with varied life history traits, from forage fish and planktivores, such as eulachon and Pacific ocean perch, to higher order piscivores, including dogfish, Pacific cod, and arrowtooth flounder. Consequently, groundfish species are present in several different trophic levels.

In the following discussion the term 'guild' is used to denote a group of trophically linked species. In the shallow guild, the spatial and diet overlap suggested that competition could occur between halibut and big skate. Based on depth preferences and diet, these two species would interact and could compete over the summer months. Halibut moves from a summer mean depth of 100 m to a winter mean of about 250-300 m. Skates tend to remain at a mean depth of 100 m year round. The seasonal diet variation for Pacific halibut, rock sole, and big skate was examined to try to determine whether the movement of dogfish out of the environment in winter has any impact on these other species. However, breadth of diet did not appear to increase for any of these species over the winter period.

In the intermediate guild, results suggested that spiny dogfish and Pacific cod could compete with one another during the summer months but are unlikely to compete with one another in winter. Similarly, English sole, Dover sole, and rex sole may impact one another during summer months. Competition is also likely between ratfish and English sole throughout the year, and between ratfish, rex sole, and Dover sole during summer. The transient habits of arrowtooth flounder and dogfish may be critical to community structure within the different spatial regions within Hecate Strait, since these two species have the highest biomass in Hecate Strait (Fargo and Tyler 1991). The diet breakdown suggests that dogfish could impact the abundance of herring, salmon, rock sole, and English sole in Hecate Strait. Arrowtooth flounder could impact herring, walleye pollock and inshore rockfish based on diet composition and could compete with dogfish, Pacific cod, petrale sole, and halibut for herring.



Odontocetes
Seals, Sea lions, Dolphins, Orcas
1
Picivorous Fish
31
Forage fish:
Herring, Sardine, Eulachon and Sandlance
90
Planktivore Fish
19
Macrobenthos and Crustaceans:
Crabs and shrimp
135
Epifauna and meiofauna:
Sea Cucumbers
103
Zooplankton:
Copepods, Euphausiids and juvenile Crustaceans
127
Detritus
44
Phytoplankton
884

Figure G.9 Energy flow for the Hecate Strait region. Boxes are proportional to group biomass in t km^{-2} year^{-1}.

5.3 Stock assessment

There are approximately 409 known species of marine fish resident off the coast of British Columbia. At least one individual of 200 of these species has been caught in the groundfish fishery over the last ten years. In this complex fishery, more than 50 species of fish are landed while 27 different groundfish species/stocks have been assessed and are subject to annual allocations in eight different management areas.

Stock assessments in recent years have been much more detailed than a decade ago. They have included decision tables where the risk associated with particular management options is quantified. This has resulted in fewer annual assessments. The recently implemented (2002) groundfish synoptic surveys will eventually provide the biological and catch-rate data that is needed to assess numerous species that have not been assessed in the past.

Issues involving groundfish fisheries have increased greatly over the last decade. The delivery of science advice now includes co-management, co-research, and stakeholder groups from industry, recreational, and conservation groups. Science partnerships have become essential for meeting the mandate of DFO and delivering core programs. These include academics in universities and scientists from other agencies. Settlement of First Nations claims may also affect management and stock assessment strategies for Pacific groundfish stocks.

6.0 EFFECT OF FISHING GEAR ON HABITAT

Habitat altered or destroyed by fishing gear produces a significant effect on the marine ecosystem. Most of the studies to date have focused on the trawl fishery, however, the longline and trap/pot fisheries also have an impact and longline and trap/pot gear is set over a larger area than that the trawl fishery occupies. Some areas of sensitive habitat have been closed to trawling (Figure G.10, Figure G.11). This encompasses the unique glass sponge reefs in the Queen Charlotte Basin (see Appendix A: Geology, Figures A.19 and A.21) and an area of gorgonian habitat in deep water off the west coast of Moresby Island in the Queen Charlotte Islands. These area closures are augmented by Marine Protected Areas, Marine parks, and Rockfish Conservation Areas.

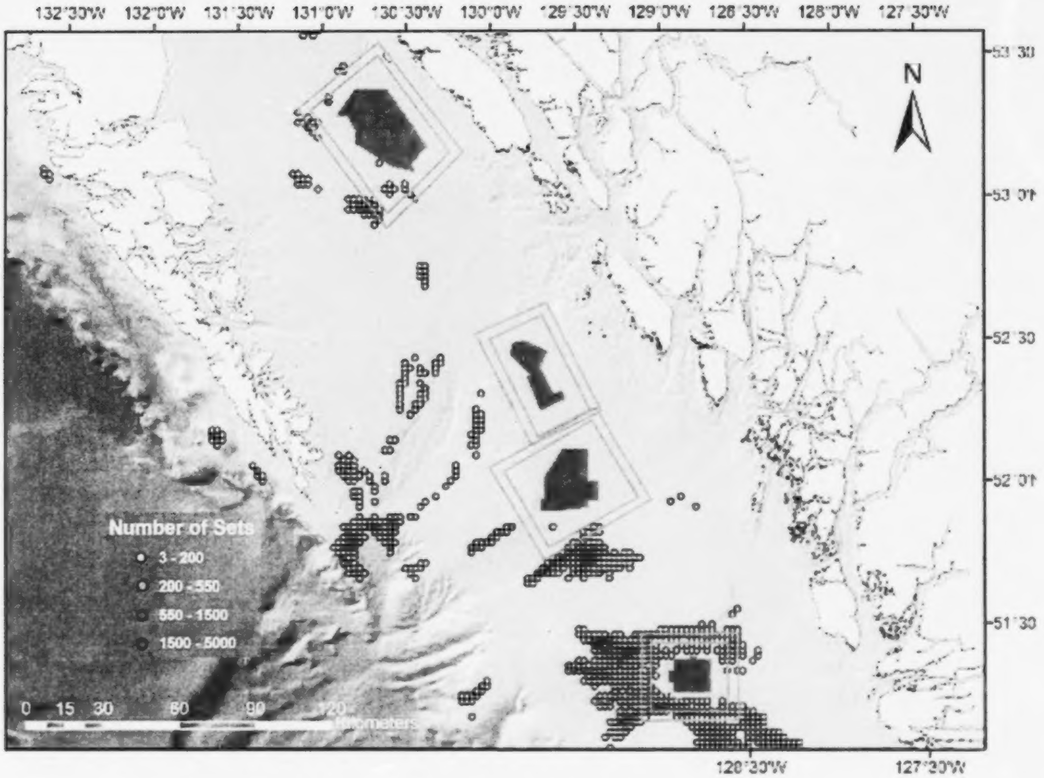

132°30'W
132°0'W
131°30'W
131°0'W
130°30'W
130°0'W
129°30'W
129°0'W
128°30'W
128°0'W
127°30'W
53°30
53°0'N
52°30
52°0'N
51°30
N
Number of Sets
3 - 200
200 - 550
550 - 1500
1500 - 5000
0 15 30 60 90 120
Kilometers
128°30'W
127°30'W

Figure G.10 Total fishing effort for the trawl fishery from 2003-2005. Shaded squares indicate fishing locations (the darker the square the greater the effort). The red areas show the location of unique glass sponge reefs in the Queen Charlotte Basin. The blue rectangles are proposed buffer boundaries for the closed areas. These areas were closed to commercial trawling in 2003.

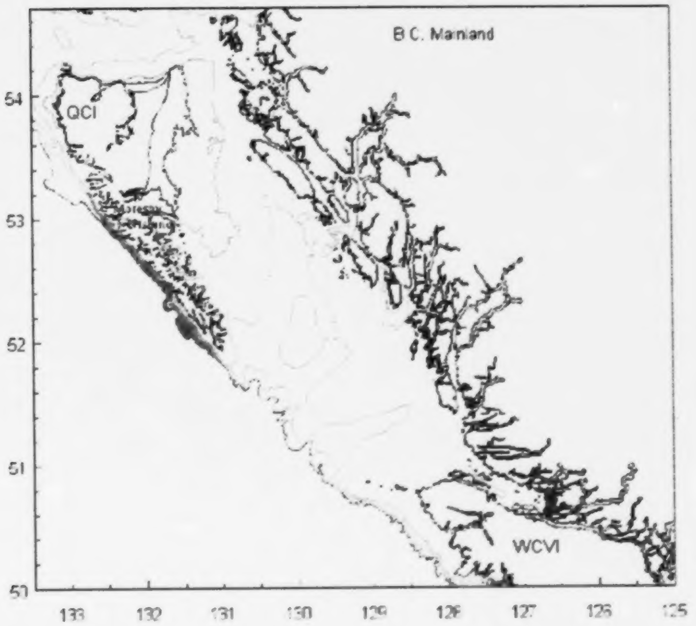


Figure G.11 Coral habitat closed to trawling (in red) off the west coast of Moresby Island in 2003.

7.0 CONSERVATION

In 1997 with the *Oceans Act* legislation, DFO made a commitment to develop a new approach to managing our oceans. An important part of this legislation has been the introduction of three principles - sustainable development, integrated management, and the precautionary approach to fisheries. We are now required to assess the effect of anthropogenic factors on marine ecosystems. The effect of fishing and loss of habitat are two important factors that can be managed by agencies like DFO. Species life history characteristics can serve as guidance for the level of sustainable exploitation for the resource.

The *Species At Risk Act* requires species conservation reports to be submitted to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). DFO staff have been directly or indirectly involved in the assessment of some groundfish species (Table G.5). COSEWIC sets priorities for species that have never been assessed or species with no recent assessment. This involves many rockfish species, which tend to be long-lived (*e.g.*, quillback to 76 years, yelloweye to 115 years). Their low rate of natural mortality and low productivity necessitates conservative harvest strategies. There are numerous examples of the depletion of rockfish stocks in the north Pacific. In BC, management regions for inshore rockfish are large, relative to stock distributions. This, combined with their sedentary habits, makes them particularly vulnerable to over fishing. These stocks may require an extremely long rebuilding period after depletion (several decades). There is little biological information available for many of these stocks, although an on-board observer program initiated in 1997, along with a series of research synoptic surveys initiated in 2003, is providing much needed biological data.

Most groundfish stocks being monitored are in a healthy state. Others, specifically lingcod and inshore rockfish stocks in the Strait of Georgia, and Pacific cod in Hecate Strait, are a conservation concern, and rebuilding strategies have been implemented. Assessment of the status of these species will be an ongoing challenge requiring new techniques (especially for rockfish) and dedicated effort by both government and resource users.

Table G.5 Summary of PNCIMA groundfish species having SARA or COSEWIC assessments, along with their most recent status.

				Status	
Group	**Common Name**	**Scientific Name**	**Year Assessed**	**SARA[1]**	**COSEWIC[2]**
Sharks	White shark	*Carcharodon carcharias*	2006		UR
	Basking shark	*Cetorhinus maximus*	2006		EN
	Bluntnose sixgill shark	*Hexanchus griseus*	2006		UR
	Brown cat shark	*Apristurus brunneus*	2006		UR
	Soupfin shark	*Galeorhinus galeus*	2006		UR
Skates	Sandpaper skate	*Bathyraja interrupta*	2006		UR
	Big skate	*Raja binoculata*	2006		UR
	Longnose skate	*Raja rhina*	2006		UR
Finfish	Green sturgeon	*Acipenser medirostris*	2004	1	SC
	Bocaccio	*Sebastes paucispinis*	2002	3	TH
	Longspine thornyhead	*Sebastolobus altivelis*	2006		UR
	Canary rockfish	*Sebastes pinniger*	2006		UR
	Rougheye rockfish	*Sebastes aleutianus*	2006		UR

[1] **SARA**: *Species at Risk Act.* 1 = on Schedule 1 legal list of wildlife species at risk; 2 = not added to legal list; 3 = referred back to COSEWIC for further information or consideration (SARA 2006).

[2] **COSEWIC**: Committee on the Status of Endangered Wildlife in Canada. EN = Endangered: facing imminent extirpation or extinction, TH = Threatened: likely to become endangered if limiting factors are not reversed; SC = Special Concern: particularly sensitive to human activities or natural events but not endangered or threatened (formerly referred to as vulnerable), UR = report under review.

8.0 INTERNATIONAL TREATY FOR PACIFIC HAKE

This treaty, signed in 2003, will ensure the sustainability of the offshore stock of Pacific hake that is shared by the United States (US) and Canada. It is also consistent with the federal government's priorities to establish cooperative working agreements that fulfill our responsibilities for the joint stewardship of trans-boundary stocks. The treaty was ratified by the US in early 2007. Canada and the US are both operating 'in the spirit' of the agreement pending full implementation.

9.0 NEW TECHNOLOGY

New technology applications are required to improve existing stock assessment capability as well as to reduce the need for destructive sampling (resulting in fish mortality). For example, it has been possible to estimate the biomass of inshore rockfish stocks using non-traditional methods. Underwater video linking fish density to habitat type, combined with side-scan sonar estimates of habitat type abundance, offers a novel means to estimate fish biomass. In situ density estimates can be obtained for some species for the first time with the use of manned submersibles and remotely operated cameras. Side-scan and multibeam sonar are providing estimates of habitat type that can be used to refine in situ density estimates.

Current assessment activities in collaboration with the fishing industry are concentrated on mitigating the effect of fishing gear on habitat and developing modern surveys capable of providing biological and catch-rate data that can be used for assessment of a wide range of species across all areas of the coast. Partnerships with universities and stakeholders are essential to ensure product delivery here.

10.0 COOPERATIVE PARTNERS

Canadian Groundfish Research and Conservation Society, Vancouver, BC.
Canadian Pacific Sardine Association, Vancouver, BC.
Canadian Wildlife Service, Sidney, BC.
Commercial Sablefish Fishermen's Association, Vancouver, BC.
Council of Haida Nations
Institute for Ocean Sciences, Sidney, BC.
International Pacific Halibut Commission, Seattle, Wa. USA.
Northwest and Alaska Fisheries Science Center, Seattle, Wa USA.
Nuu-Chah-Nulth Nations
Pacific Geoscience Centre, Sidney, BC.
Pacific Halibut Management Association, Vancouver, BC.
Parks Canada, Sidney, BC.

Simon Fraser University (REM Faculty), Burnaby, BC.
University of British Columbia (Fisheries Centre), Vancouver, BC.
University of Victoria, Victoria, BC.
World Wildlife Fund, Vancouver, BC.

11.0 GLOSSARY

Annelid – Elongated, segmented invertebrate; including earthworms and leeches.

Anthropogenic – Caused or produced by humans.

Benthivore – Eat bottom-dwelling flora and fauna.

Carnivore – An organism that eats meat.

Chemosynthesis – Chemosynthesis is the biological conversion of 1-carbon molecules (usually carbon dioxide or methane) and nutrients into organic matter using the oxidation of inorganic molecules (*e.g.*, hydrogen gas, hydrogen sulfide) or methane as a source of energy, rather than sunlight, as in photosynthesis. Large populations of animals can be supported by chemosynthetic primary production at hydrothermal vents, methane clathrate cold seeps, and whale falls.

Cnidaria – An animal phylum that includes hydra, sea anemones, jellyfish, and hydrozoan colonies.

Demersal – Organisms that live on or near the ocean bottom.

Echiurans – Echinoderms, marine invertebrates with tube feet and five-part radially symmetrical bodies.

Fecundity – The potential reproductive capacity of an organism or population.

Guild – A group of species having similar ecological resource requirements or foraging strategies.

Iteroparous – Able to spawn many times during their lifetime.

Ontogenetic variability – The variability in the origin or development of an organism from embryo to adult.

Pelagic – Refers to fish and animals that live in the open sea, away from the sea bottom.

Phenotypic plasticity – Is non-genetic variation in organisms in response to environmental factors. Marine fish species have evolved many reproductive strategies including: batch and indeterminate spawners, brief to protracted spawning period, pelagic and demersal eggs, and differences in fecundity.

Piscivore – An organism that eats fish.

Planktivore – An animal which feeds primarily on plankton; plankton is the collective group of tiny plants and animals that float or drift near the surface of a body of water; plankton is very low on the aquatic food chain and therefore a vital element in that ecosystem.

Trophic – Pertaining to nutrition or to a position in a food web, food chain, or food pyramid.

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Canadian Technical Report of
Fisheries and Aquatic Sciences 2667

2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX H: PELAGIC FISHES

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1.0 INTRODUCTION

Pelagic fishes are those species that spend most of their adult life near the surface or in the water column. Tuna and billfishes are species considered typical pelagics in offshore waters. In the coastal zone, characterized by the Pacific North Coast Integrated Management Area (PNCIMA; Figure H.0), there are both shallow and deeper water components. The pelagic species in this area include a number of resident 'forage' species that occur in the shallower inshore waters as well as seasonal transient visitors (Table H.0). The seasonal species are either typically offshore pelagics that intermittently venture into PNCIMA when oceanic conditions permit (albacore tuna, bonito, pomfret, sunfish, and saury), or migrants from the south (sardine, anchovy, shad, hake, mackerel, and salmonids such as coho) that spend the summer feeding in PNCIMA before returning south to breed. However, in this chapter, we focus on the resident or coastal species, most of which are small, abundant, schooling, forage fishes. A few key migratory species are also described: Pacific sardine, American shad, northern anchovy, and albacore tuna. Pacific hake and salmonids, while pelagic, are discussed in the groundfish and salmon appendices, respectively.

The coastal pelagic forage species discussed in detail are comprised of five families. Possibly the most ecologically important species in PNCIMA are the Clupeidae represented by Pacific herring (*Clupea pallasii*). The Ammodytidae are represented by sand lance (*Ammodytes hexapterus*), which is also believed to be ecologically important but is not well studied. The Embiotocidae, or surfperches, are represented by several species and are treated as a group. The Osmeridae, or smelts, are represented by a few important species: the anadromous eulachon (*Thaleichthys pacificus*), capelin (*Mallotus villosus*), and surf smelt (*Hypomesus pretiosis*). The northern smoothtongue (*Leuroglossus schmidti*) is a member of the Bathylagidae, the deepsea smelts, and represents the mesopelagics, a potentially important but poorly studied group. Brief synopses of these species can also be found in Hart (1973), Gillespie (1993), or Stocker *et al.* (2001).

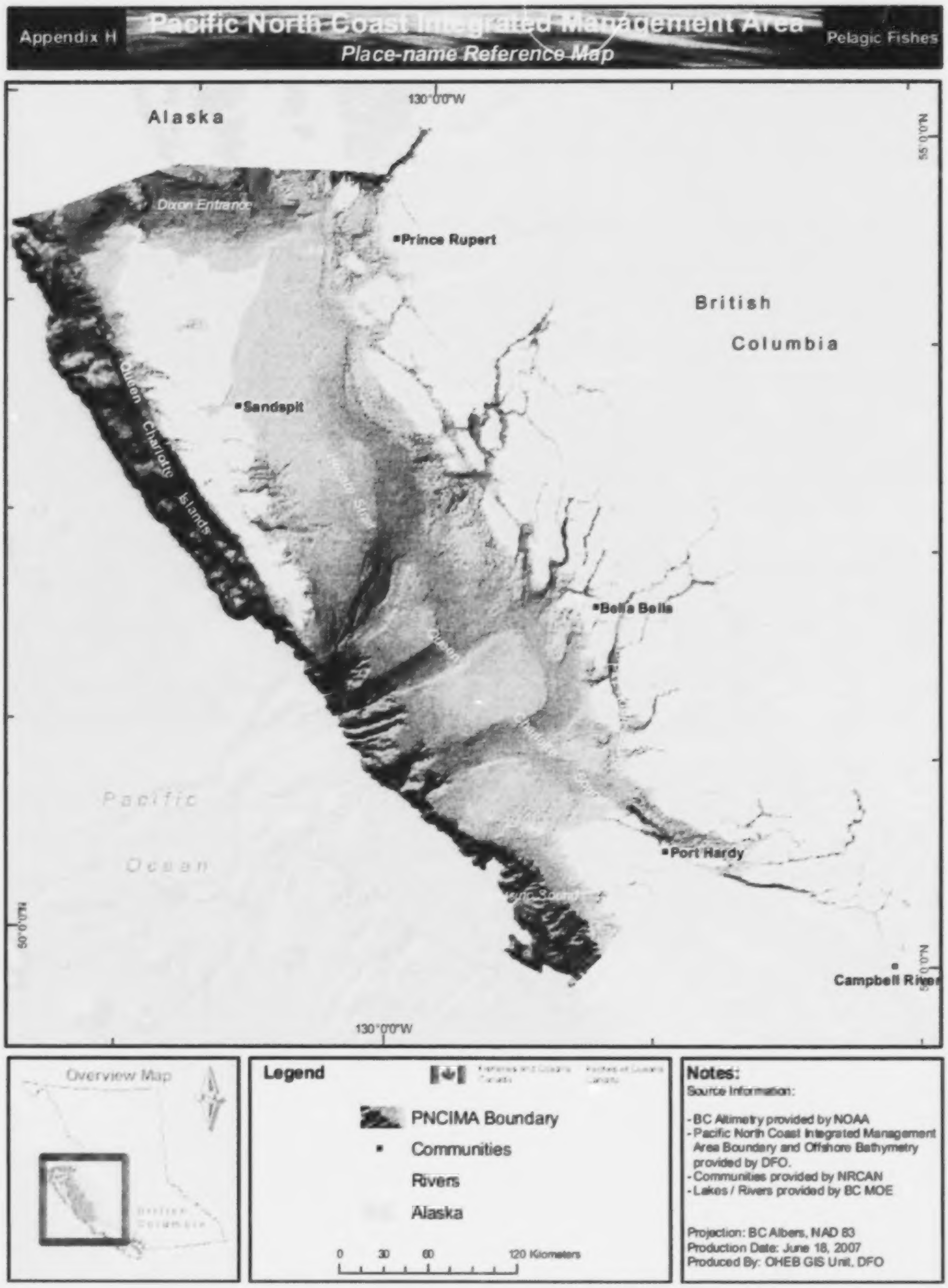

Appendix H
Pacific North Coast Integrated Management Area
Place-name Reference Map
Pelagic Fishes
130°0'0"W
55°0'0"N
50°0'0"N
Alaska
Dixon Entrance
Prince Rupert
British
Columbia
Sandspit
Queen Charlotte Islands
Bella Bella
Pacific
Ocean
Port Hardy
Campbell River
Overview Map
Legend
PNCIMA Boundary
Communities
Rivers
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure H.0 PNCIMA region showing locations and features of BC waters.

Table H.0 General occurrence and taxonomic classification of pelagic fish species found in the PNCIMA ecosystem. Other pelagic fish such as salmonids, sharks, Pacific hake, pollock, and midwater rockfishes are discussed in the salmon and groundfish appendices.

Phylum Chordata
Class Osteicthyes

COMMON NAME	PRIMARY HABITAT**	FAMILY	GENUS & SPECIES
Pacific herring+	Offshore<->Inshore	Clupeidae	*Clupea pallasii*
Sand lance+*	Inshore	Ammodytidae	*Ammodytes hexpterus*
Surfperches+		Embiotocidae	
Pile perch	Inshore<->Offshore		*Rhacochilus vacca*
Shiner perch	Inshore<->Offshore		*Cymatogaster aggregata*
Striped seaperch	Inshore		*Embiotoca lateralis*
Kelp perch	Inshore		*Brachyisticus frenatus*
Redtail surfperch	Inshore		*Amphistichus rhodoterus*
Walleye surfperch	Inshore		*Hyperprosopon argenteum*
Silver surfperch	Inshore		*Hyperprosopon ellipticum*
White seaperch	Inshore		*Phanerodon furcatus*
Smelts		Osmeridae	
Eulachon+	Offshore<->In-river		*Thaleichthys pacificus*
Capelin+*	Inshore		*Mallotus villosus*
Surf smelt+	Inshore		*Hypomesus pretiosus*
Whitebait smelt	Inshore		*Allosmerus elogatus*
Rainbow smelt	Inshore		*Osmerus mordax*
Night smelt	Inshore		*Spirinchus starski*
Longfin smelt	Inshore		*Spirinchus thaleichthys*
Seasonal pelagic fish			
Pacific sardine+	Offshore->Inshore	Clupeidae	*Sardinops sagax*
Northern anchovy+*	Offshore->Inshore	Engraulidae	*Engraulis mordax*
American shad+*	Offshore->In-river	Clupeidae	*Alosa sapidissima*
Albacore tuna+	Offshore, oceanic	Scombridae	*Thunnus alalunga*
Chub mackerel	Offshore->Inshore	Scombridae	*Scomber japonicus*
Pacific bonito	Offshore, oceanic	Scombridae	*Sarda chiliensis*
Jack mackerel	Offshore->inshore	Carangidae	*Trachurus symmetricus*
Pacific pomfret	Offshore, oceanic	Bramidae	*Brama japonica*
Ocean sunfish	Offshore, oceanic	Molidae	*Mola mola*
Pacific saury	Offshore, oceanic	Scomberesocidae	*Cololabis saira*
Deepsea smelts			
Northern smoothtongue+*	Inshore, Mesopelagic	Bathylagidae	*Leuroglossus schmidti*

+ Species or family discussed in this chapter
* Non-commercial species in British Columbia
** <-> indicates annual offshore to inshore movement, -> indicates seasonal movement from offshore to inshore habitat.

2.0 PACIFIC HERRING

Clupea pallasii (Valenciennes 1847)

Pacific herring (*Clupea pallasii*) is a north temperate species ranging from the Yellow Sea on the Asian coast north through the Bering Sea and into the Arctic Ocean. On the North American coast, herring are found from the Beaufort Sea south to southern California (Haegele and Schweigert 1985). Herring is a migratory pelagic species occurring in both offshore and inshore waters. Within PNCIMA, three major migratory herring populations are recognized and managed separately: the Queen Charlotte Islands, the Prince Rupert District, and the Central Coast (Figure H.1). Additional minor herring populations occur throughout the PNCIMA area (Hay and McCarter 2002) but only the stocks on the west coast of the Queen Charlotte Islands and those spawning in Quatsino Sound (NW Vancouver Island) are managed individually. The two major herring populations in southern BC spawn on the West Coast of Vancouver Island (WCVI) and in the Strait of Georgia (SOG). Major and minor herring spawning sites are spread throughout the entire coast of British Columbia (BC) (Figure H.2).

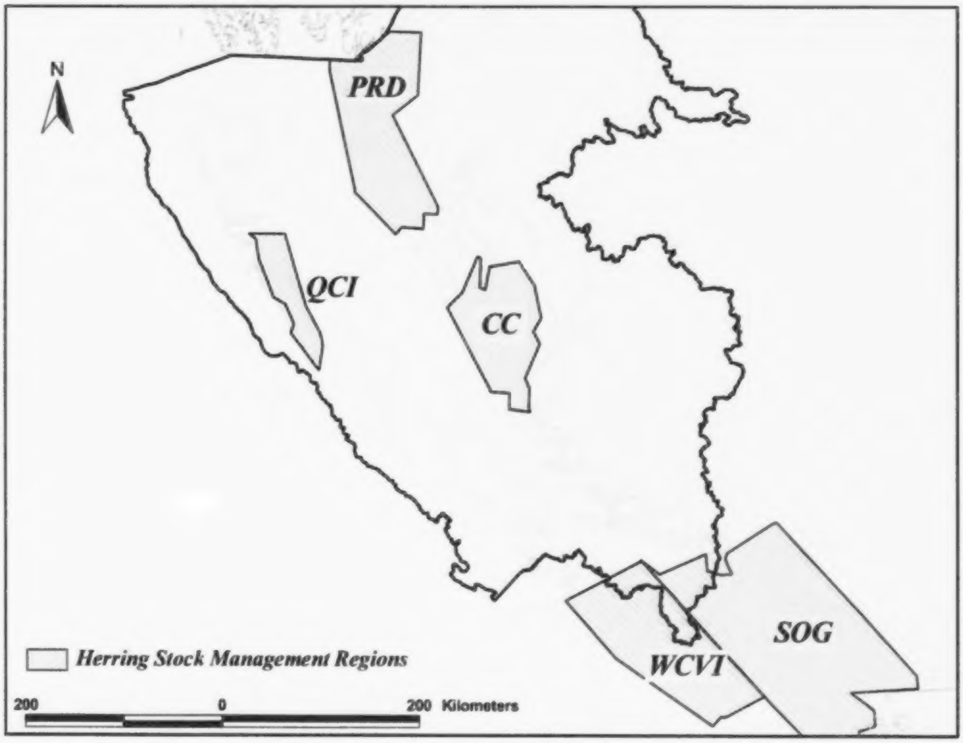
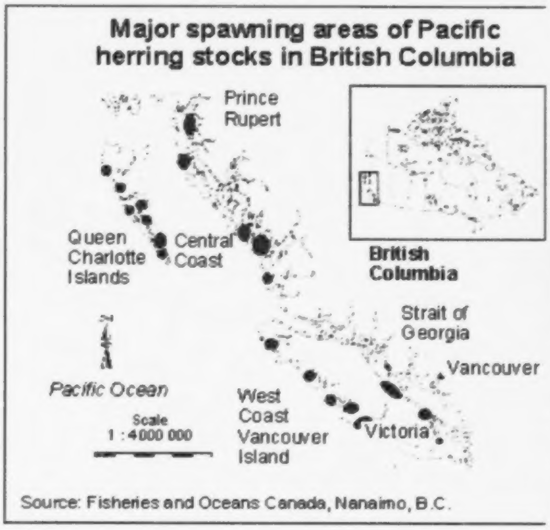


Figure H.1 The major herring stock assessment regions. Source: Fisheries and Oceans Canada, Stock Assessment Division, Nanaimo, BC.

Pacific herring is a schooling species with populations that undertake both short range (within inlets) and longer range migrations (offshore). It is relatively short-lived, with a maximum recorded age of 15 years, although most fish live only 7-8 years (Hourston and Haegele 1980). Throughout its distribution, herring become sexually mature predominantly between the ages of two and five. Within its range, the age of recruitment tends to increase with latitude (Stocker *et al. eds*. 2001). Most BC herring mature at age three. Inshore spawning migrations occur during October to December from offshore feeding grounds, (west coast of Vancouver Island in the south and Hecate Strait in the north), towards inshore spawning grounds. Herring congregate in large schools in the vicinity of spawning areas over the winter awaiting final maturation (Hay 1985; Fisheries and Oceans Canada 1994; Haegele and Schweigert 1985). On the BC coast, herring spawn in late winter, from February to as late as July, with the majority of spawning occurring in March and early April, on beaches from the high tide mark down to 20 m in the subtidal. Female herring consistently produce an average of 200 eggs g^{-1} of female weight in all areas of the BC coast (Hay 1985). Spawn deposition occurs in high-energy environments, on intertidal and shallow subtidal bottom substrate and vegetation. Both sexes of Pacific herring make physical contact with the spawning substrate onto which adhesive eggs are deposited (Haegele and Schweigert 1985). Males release milt directly into the water, which produces a milky white discolouration on the spawning grounds (Figure H.3). Temperature and salinity are important in determining when and where herring spawn occurs, and subsequent survivorship. Eggs are generally tolerant to temperatures ranging from 5-15 °C and a salinity range of 3-33‰ (Haegele and Schweigert 1985).


Major spawning areas of Pacific herring stocks in British Columbia
Prince Rupert
Queen Charlotte Islands
Central Coast
British Columbia
Strait of Georgia
Vancouver
Pacific Ocean
Scale 1 : 4000 000
West Coast Vancouver Island
Victoria

Source: Fisheries and Oceans Canada, Nanaimo, B.C.

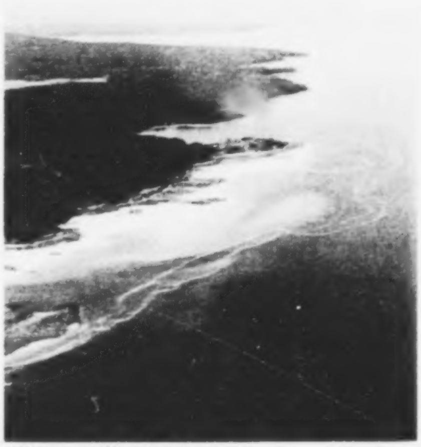


Photo credit: N. Akune

Figure H.2 Pacific Canada's major coastal spawning areas of Pacific herring stocks in British Columbia.

Figure H.3 Herring spawns observed along the eastern shores of Hornby Island.

Eggs hatch in 10-21 days, releasing 7-8 mm larvae. Larvae concentrate in the surface layers (0-20 m depth) near shore, aggregated by currents. At about 25 mm, metamorphosis to the adult form occurs in conjunction with schooling. At this stage, herring begin diurnal migrations, descending to deep water during the day, and rising to the surface at night. Offshore migration by juvenile herring begins in some areas in the fall of their first year and in other areas late the following spring (Hourston and Haegele 1980). Foraging adults are most commonly found in deeper waters (80-180 m) along the edges of offshore banks (*e.g.,* Goose Island Bank). Herring are about 100 mm in length at the end of their first year, and ~180 mm at sexual maturity. Most adults range from 175-250 mm in length at 3-8 years of age (Taylor 1964).

Herring have a long history of commercial exploitation dating back to at least 1877. In the early 1900s the expanding fishery was focused on providing bait for other fisheries and by the 1920s was exporting a dry salted product to the Orient (Taylor 1964; Hourston and Haegele 1980). In the early 1930s a rapidly expanding reduction fishery was exploiting all of the herring stocks coast wide leading eventually to a collapse and fishery closure in 1968 (Hourston 1980). The modern roe herring fishery began in 1972 and has continued to present harvesting a maximum of 20% of the forecast biomass providing that it exceeds the fishing threshold (Schweigert 2004). There are currently four fisheries that target Pacific herring: roe, spawn-on-kelp, special use, and food and bait (Rusch *et al.* 2003). These fisheries utilize only two gear types, purse seine and gillnet. The roe fishery is the largest, focusing on a specialty market in Japan and harvesting about 25-30,000 tonnes of herring annually. Spawn-on-kelp (SOK) is primarily a First Nations' fishery that impounds herring to induce spawning on kelp to provide a specialty product to Japanese consumers (Hourston and Haegele 1980). It produces an average of 250-300 tonnes of spawn-on-kelp each year. The food and bait and special use fishery are marginal, harvesting about one thousand tonnes each, primarily for food and commercial and sports bait. However, only the roe and SOK fisheries are active in the PNCIMA area. The management of these fisheries was reviewed by Stocker (1993).

The abundance of the five major herring populations (Figure H.1) is assessed annually by surveying herring spawning beds and hind-casting abundance from observed egg numbers and knowledge of population fecundity, sex ratio, and age structure using catch-age analysis (Schweigert 2004). In total, the mature biomass of herring in the PNCIMA area averages about 100,000 metric tonnes. Herring populations may undergo large inter-annual fluctuations in abundance (Figure H.4), largely as a result of variation in recruitment of first time spawners. The survival of herring from the egg to the age of sexual maturity varies as a function of oceanographic conditions that affect availability of food and the impact of predators on juvenile herring (Schweigert and Noakes 1991; Schweigert 1997). For herring populations in southern BC, sea surface temperature is inversely related to recruitment of herring to the spawning population (Ware 1991; Schweigert 1993). It appears that during warm years, a greater influx of predators from the California Current system has a negative effect on herring survival off the west coast of Vancouver Island.

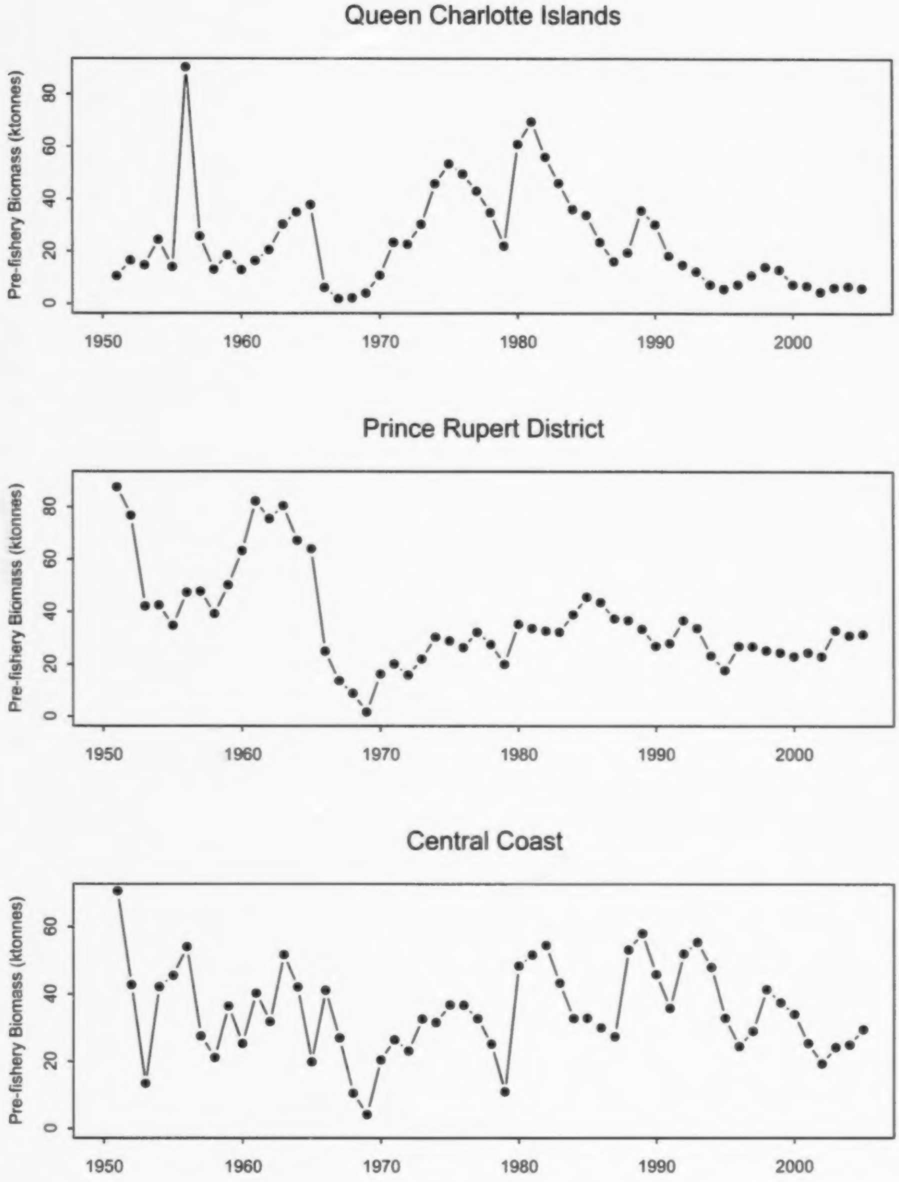


Figure H.4 Estimates of pre-fishery spawning stock biomass for northern BC herring stock assessment regions, 1951-2005.

Pacific herring are an essential component of a complex coastal marine food web in the PNCIMA region. During their larval to juvenile phase, their diet changes from invertebrate eggs, copepods and diatoms to slightly larger prey items such as barnacle larvae, mollusc larvae, bryozoans, rotifers, and young fishes. Copepods remain the most important prey item until about midway through the first year of life, when euphausiids become the key component of their diet for the remainder of their life. Many species of marine fish, birds, and mammals prey upon herring at each life stage (egg, larva, juvenile, and adult) (Hourston and Haegele 1980). Herring is a major prey item of Pacific cod, halibut, lingcod, coho salmon, and harbour seals, and contributes 30-70% to the summer diet of adult chinook salmon. Herring and their seasonal spawn depositions are an important part of the diet of invertebrates, as well as eagles, migrating seabirds, and grey whales, providing plentiful energy during breeding seasons (Hall *et al.* 2004; Booth 2000).

3.0 PACIFIC SAND LANCE

Ammodytes hexapterus (Pallas 1814)

Pacific sand lance are distributed throughout coastal areas of the North Pacific from Baja California to the southern Beaufort Sea and westward into the Sea of Japan and Sea of Okhotsk (Hart 1973). Robards *et al.* (1999b; 2002) reported that the highest abundances have been found near fine sand or gravel burrowing habitat that is sheltered from disturbance by storm waves, in areas where bottom currents keep oxygen levels high and at depths of less than 50 m. Although some summer-fall, offshore-inshore movements have been observed prior to spawning, most adult populations are thought to forage and spawn in close proximity to their burrowing habitat (Hobson 1986; Robards *et al.* 1999a; 1999b). Two characteristic defense tactics against predation are burrowing into sand and balling up into tightly packed schools (Robards *et al.* 1999b).

The Pacific sand lance is a small, elongate, tubular schooling forage fish up to 20 cm long. Mortality at all life stages is high, especially from predation, and its maximum life span is usually no more than five years, although it is capable of living upwards of seven years (Robards *et al.* 1999b). Most fish reach sexual maturity at two years of age and then spawn annually in dense schools in the intertidal or subtidal zones. They spawn primarily in the fall (observations from Prince William Sound, Alaska indicate August to October) and females deposit slightly adhesive eggs near or on bottom substrates and many of the spawned eggs mix into beach substrate, which is thought to provide some protection against predators and desiccation (Pentilla 1995). Embryos generally develop into larvae within 1-2 months, depending on ambient temperatures (Field 1987), and larvae develop into juveniles by early spring peaks in planktonic prey abundance (Robards *et al.* 1999d).

Although this species is relatively widespread and prevalent in most inshore waters of BC with sand-gravel substrates, no stock assessment data are available to provide information on stock trends. Sand lance are difficult to sample with most traditional sampling gear, but are frequently taken as bycatch in trawls. Relative abundance can be inferred from their prevalence as prey in seabird colonies on localized scales (Litzow *et al.* 2000;

Bertram 1999). Sand lance can be captured intertidally by beach seining or digging up substrate at low tides (Robards *et al.* 1999a; 1999c). SCUBA diving has been used to assess relative abundance in localized areas (Golet *et al.* 2002). No commercial fisheries currently exist in BC for sand lance, although small harvests for food occur in Japan and they are captured for bait in the United States. Sport fishing for sand lance has been permitted in BC, but there has been negligible catch effort.

Adult sand lance feed on a variety of prey, such as copepod zooplankton, epibenthic invertebrates, fish larvae and eggs (such as herring). Larvae feed on phytoplankton and early zooplankton stages. Sand lance is an important prey species for many fish, seabirds, and marine mammals throughout much of its range because of its apparent abundance and nutritional content (Field 1987; Robards *et al.* 1999a; 1999b; 1999c; Golet *et al.* 2002; Iverson *et al.* 2002; Pearsall and Fargo 2007). Prominent fish predators include: Pacific halibut and many other flatfish (arrowtooth flounder, speckled sand dab, English sole, rock sole, butter sole, and sand sole); sablefish; Pacific cod; skates (big and longnose); spiny dogfish; rockfish (redbanded and yellowtail), and salmon (McFarlane *et al.* 1984; Field 1987; Pearsall and Fargo 2007). Seabird predators include scoters, cormorants, auklets, loons, murres, pigeon guillemot, and grebes, and marine mammal predators include sea lions, seals, and humpback whales (Field 1987; Robards *et al.* 1999b; Golet *et al.* 2002; Gregr 2004).

4.0 SURF PERCH

Embiotocidae

The surfperch family (*Embiotocidae*) consists of twenty marine and one freshwater species, most of which are restricted to the eastern Pacific with the number of species increasing from north to south (Lane *et al.* 2002). There are eight species in BC, four species are distributed coast wide (Table H.1) and include the pile perch (*Rhacochilus vacca*), shiner perch (*Cymatogaster aggregata*), striped seaperch (*Embiotoca lateralis*), and kelp perch (*Brachyistius frenatus*). Four additional species are restricted to southern Vancouver Island (their northern range limit) and include the redtail surfperch (*Amphistichus rhodoterus*), walleye surfperch (*Hyperprosopon argenteum*), silver surfperch (*H. ellipicum*), and white seaperch (*Phanerodon furcatus*).

All members of the family are viviparous, with females giving birth to highly developed, free-swimming young (Turner 1947). Most species will rarely give birth to more than 20 individuals, but fecundity is size and species dependent (Cannon 1956; Lane *et al.* 2002). Gestation periods are relatively long due to this live-bearing life history strategy. Often as much as 5 months are required to develop the young. Maturity for most species is reached at 1-2 years of age, with a maximum age of 6-10 years. The pile perch is the largest species at approximately 1 kg and the oldest at 10 years. Surfperch generally are widespread, inshore species occupying a variety of habitats including sandy beaches, rocky shorelines and reefs, kelp beds, and estuaries (Tarp 1952; Roedel 1953; Hubbs and Hubbs 1954; Peden 1966; Hobson 1971; Feder *et al.* 1974; Hobson and Chess 1986; Lamb and Edgell 1986; Anderson 1994; Anderson and Sabado 1999), with water temperature being the primary factor affecting distribution (Karpov *et al.* 1995).

Table H.1 Biological and habitat characteristics of four common commercial surfperch.

Species	Length	Habitat	Depth
Shiner Perch	To 15 cm	Pilings and floats, in bays and kelp beds	Surface to 150 m
Striped perch	To 37.5 cm	Rocky reefs and pilings, in kelp beds	Surface to 20 m
Pile Perch	To 43 cm	On floats, pilings and reefs	Surface to 80 m
Kelp Perch	To 22 cm	Kelp beds	Surface to 20 m

(Source: Harbo 1999)

Due to extremely low fecundity, maintenance of populations is likely dependent upon a high survival of the young (Quinnell 1986). Thus, surfperch are believed to be prone to overfishing and slow population recovery. Overfishing may have already occurred in California, where recreational and commercial catches have steadily declined since the 1960s (Fritzsche and Collier 2001). In BC, surfperch are landed in both recreational and commercial fisheries, the latter mostly as bycatch (Lane *et al.* 2002). Recreational fishing for surfperch is common, especially on wharves, docks, and piers where younger anglers can participate. In contrast, a specialized commercial fishery exists for surfperch in BC. Catches are mainly by beach seine (hook-and-line and dip-nets also are permitted) which has raised concerns regarding bycatch of non-target species, especially salmonids, and negative impacts on nearshore habitats through destruction of macrophytes (*e.g.*, eelgrass beds). Shiner perch are routinely caught as bycatch in the shrimp trawl fishery, including the Prince Rupert District fishery, but catch rates are considerably lower in the north compared to the south, especially the Strait of Georgia (Hay *et al.* 1999). The fisheries are managed under an integrated fishery management plan (IFMP) that enforces a seasonal spawning closure from May 15 to August 30 and significantly limits directed effort. Commercial fishers are required to submit logbooks of their activity and harvest. Limited understanding of the species biology and population dynamics especially of harvested populations is an area of concern. Low reproductive capacity makes the species susceptible to serial depletion even under relatively low levels of exploitation.

The species in this family have developed specialized feeding niches that limit competition within nearshore environments (DeMartini 1969). Surfperch are usually bottom or pile grazers, but are known to feed throughout the water column. Typical prey items are primarily small invertebrates including molluscs (bivalves and gastropods), isopods, amphipods, decapods, and polychaetes (Hubbs and Hubbs 1954; Gordon 1965; Gnose 1967; Feder *et al.* 1974; Lane *et al.* 2002). Surfperch are prey for a variety of predators including sea birds, otters, pinnipeds, and a variety of marine fish including rockfish and lingcod (Odenweller 1975; Stenson *et al.* 1984; Karpov *et al.* 1995).

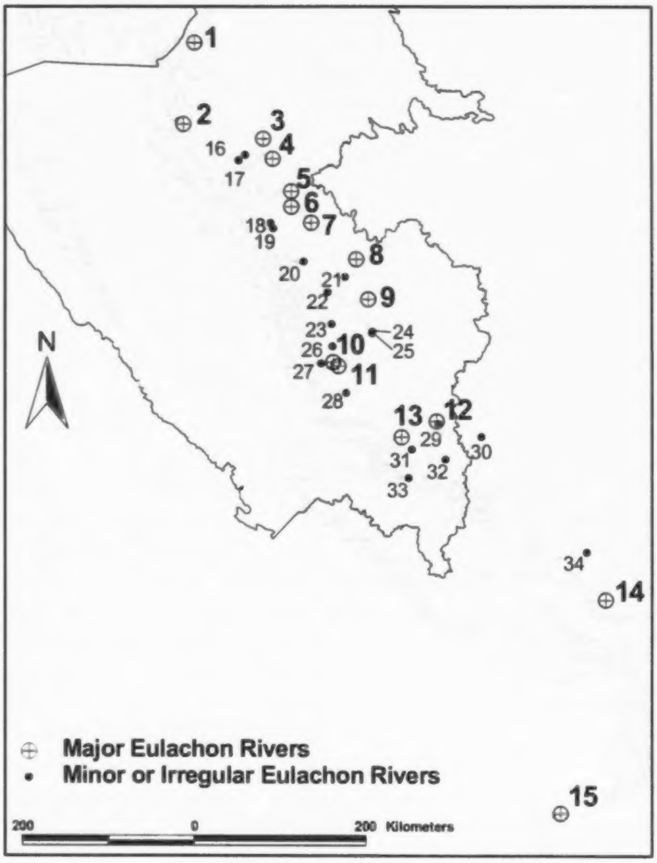
5.0 EULACHON

Thaleichthys pacificus (Richardson 1836)

Eulachon (*Thaleichthys pacificus*) is a small, anadromous smelt distributed in the Pacific Ocean from northern California to the southern Bering Sea. Eulachon spend up to 95% of their life in the ocean and return to freshwater streams and rivers to spawn. Over thirty spawning rivers are distributed along the entire west coast of BC (Figure H.5). As recently as 1999, new rivers have been identified as supporting eulachon runs, where they had not previously been documented (McCarter and Hay 1999). Thirty (or 88%) of the spawning rivers indicated in Figure H.5 are located in the PNCIMA region, including 13 of the 15 rivers classified as having regular or sustained runs. The largest eulachon run in the world occurs in the Columbia River (January-February) in Washington State. The Fraser River (April-May) and Nass River (March) have particularly large runs compared to other BC runs, which typically occur in March. Adult eulachon return only to rivers that drain major snow packs or glaciers (snow-dominant watersheds). These rivers are characterized by predominant spring flooding or freshets. Eulachon spawning rivers are also associated with coastal temperate rainforests (Hay and McCarter 2002). There are no sustained eulachon runs in rainfall-dominated watersheds (*i.e.*, rivers that drain Vancouver Island or Queen Charlotte Islands) that have predominant fall freshets following heavy rains in November and December (Hay *et al.* 2002).

The marine distribution of adults in BC includes the deeper portions of the continental shelf around Dixon Entrance, Hecate Strait, Queen Charlotte Sound, and the west coast of Vancouver Island, generally at depths of 80-200 m. Eulachon, like Pacific salmon, are anadromous (hatch in streams, migrate to the ocean, and return to their natal streams to spawn). Eulachon are also believed to be semelparous, meaning they die soon after spawning (Hay and McCarter 2000; Stoffels 2001). Spawning activity is limited to the lower reaches of suitable rivers. Females deposit approximately 30,000 small, adhesive eggs that attach themselves to sand grains and pebbles. At ambient temperatures (3-10 °C), eggs hatch within 3-5 weeks. The small larvae (4-6 mm) are quickly swept out into the marine environment. Age determination remains difficult, so it is not possible to accurately determine the length of time spent at sea before maturing, but it is thought to be 2-5 years. There is a large incidence of post-spawning mortality. Adults reach a length between 15-20 cm, and weigh between 40-60 grams (Hay *et al.* 2002; DFO 1999; Stocker *et al. eds*. 2001). Eulachon biology and distribution along the Pacific coast of Canada was reviewed in detail and summarized by Hay and McCarter (2000) (Fisheries and Oceans Canada 2002a).

Eulachon is of particular significance to First Nation communities as a culturally and spiritually important diet staple. They are very high in oil content and were commonly referred to as candlefish because of their ability to incinerate after drying. Eulachon fishery landings from the Fraser River during the mid-1900s were in the range of several hundred tonnes and were utilized mostly for animal feed and meal. In the 1980s, ten to fifty tonnes were harvested annually and much of the product was directed at the fresh fish market or used as bait. First Nation food fisheries also occur on the Fraser River and on most other major spawning rivers along the BC coast. Nass River annual catches, for example, have been in the range of 100-300 tonnes, but have recently declined in 2006. All fishing is done during the spawning run. At the peak of the run, fish are caught by dipnet, trap, seine, or gillnet. Since 2000, several eulachon runs in the PNCIMA region (runs 3, 8, 9, 10, and 11 in Figure H.5) have been declared insufficient to support even food, social, and ceremonial First Nations' fisheries. Eulachon harvests in the Columbia River in Washington State have been the largest on the west coast of North America, approximately 1,000 tonnes per year until the mid-1990s, declining to less than 10 tonnes in 2006.



Stream Name	#
Nass	**1**
Skeena	**2**
Kitimat River	**3**
Kildala River	**4**
Giltoyees Inlet	16
Foch Lagoon	17
Kitlope River	**7**
Kowesas River	**6**
Kemano/Wahoo River	**5**
Khutze River	19
Aaltanhash River	18
Kainet or Lard Creek	20
Bella Coola River	**9**
Kimsquit/Dean Rivers	**8**
Noeick River	24
Taleomy River	25
Skowquiltz River	21
Cascade Inlet	22
Kwatna River	23
Chuckwalla/Kilbella	**10**
Wannock/Oweekeno	**11**
Clyak River, Moses Inlet	26
Hardy Inlet (unknown source)	27
Nekite River, Smith Inlet	28
Kingcome River	**13**
Kakweiken River	31
Klinaklini River	**12**
Franklin River	29
Port Neville	33
Stafford/Apple Rivers	32
Homathko River	30
Squamish River	34
Fraser River	**14**
Columbia River	**15**

Figure H.5 Eulachon bearing rivers along the British Columbian coast (listed from north to south; major rivers in bold). Source: Fisheries & Oceans Canada, Habitat and Enhancement Branch, Nanaimo, BC.

Declines in eulachon spawning runs were observed from California to southeast Alaska during the early to mid 1990s (Hay and McCarter 2000). Monitoring of eulachon in BC waters is limited, so that some declines were not well documented or confirmed. In recent years, particularly since 1994, eulachon abundance has declined synchronously in many rivers and virtually disappeared in California. This decrease has been noticeable in the PNCIMA region, with very poor runs in Douglas Channel, Gardner Canal, Dean/Burke channels, and Rivers Inlet areas in the past five years. It is suspected that these declines may be related to large-scale climate change. Recent studies suggest rivers that normally experience spring freshet events may gradually be changing to summer and fall freshets that may impair eulachon spawning runs (D.E. Hay, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2004). Declining abundance is not coast wide, as medium to good runs were observed in various southeast Alaska rivers, the Columbia, Nass, Skeena, Klinaklini, Kingcome, and Fraser rivers between 2001 and 2002. However, the Fraser River has experienced a steady decline from 2002 to 2005 and is presently at a historic low level (Therriault and McCarter 2005). Temporary increases in the abundance of eulachon in offshore waters of BC and parts of Alaska occurred during 2001-2002 but have subsequently declined in some of these areas. Bycatch is monitored during annual shrimp trawl research surveys and in shrimp trawl fisheries (D. Rutherford, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2004). In recent years the shrimp trawl industry has adopted bycatch reduction devices but their efficacy remains uncertain.

Eulachon have been an important component of the coastal ecosystem. Larval eulachon feed on copepod larvae, adding phytoplankton, mysids, ostracods, barnacle larvae, cladocerans, and worm larvae, as well as cannibalizing their own species, as they grow (Hart 1973). Juveniles and adults feed on copepods and euphausiids. Eulachon are important prey for dogfish, sturgeon, halibut, Pacific cod, porpoise, finback whale, killer whale, seals, sea lions, gulls, and other piscivorous birds during their annual spawning migration (Hart 1973). At other times, they are an important food item for fur seals and salmonids off the west coast of Vancouver Island.

6.0 CAPELIN

Mallotus villosus (Muller 1776)

Capelin (*Mallotus villosus*) belongs to the smelt family. Their distribution on the Pacific coast extends from Juan de Fuca Strait, north through Alaska and into the Arctic Ocean. Relatively little is known about capelin in the BC waters of the northeast Pacific Ocean; they are more closely monitored and studied in Alaska and Atlantic Canada where they are more common. Fall spawning capelin were observed throughout the 1930s to 1970s from several Strait of Georgia beaches near Nanaimo, Denman Island, and Ladner (D.E. Hay, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2004) based on reports from local residents and fishermen. They subsequently disappeared from these waters, but in the late 1990s, there was an unprecedented influx of capelin into the northern and southern portions of Johnstone Straits as they were frequently captured in purse seine sets and in trawl surveys in the lower PNCIMA region.

Capelin are not utilized commercially in BC; however, they have been recreationally harvested on local beaches. Spawning occurs at high tides often during the full moon in late September or early October. They spawn on beaches with fine gravel, often with groundwater seepage. Fertilized eggs, measuring approximately 1 mm in diameter, stick to the gravel and will hatch within 2-3 weeks, producing slender, 4-5 mm larvae. Little is known of their life history in BC, but elsewhere, capelin live 3 or more years. Specimens captured in the mid-1990s in Bute and Knight inlets were in a ripe condition in March, suggesting the occurrence of spring as well as fall spawning populations (Hay 1998). Adults feed primarily on euphausiids and copepods. In BC, this species is not common enough to be an important food source for most fishes, although it is known to be eaten by chinook and coho salmon (Hart 1973). In the North Atlantic Ocean capelin are widely distributed and are a very important food source for Atlantic cod and harp seals. Capelin are near the southern extent of their range in PNCIMA and not especially abundant. Consequently, they are unlikely to play a significant role in this ecosystem.

7.0 SURF SMELT

Hypomesus pretiosus (Girard 1954)

Surf smelt, *Hypomesus pretiosus*, is a small, silvery, pelagic schooling fish and one of seven representatives of the family Osmeridae in BC, with a distribution that extends from Monterey Bay, California to Prince William Sound, Alaska. Scientific data on the distribution of surf smelt in BC is sparse. They are known to occur in protected areas of the north coast, although they are most abundant in the Strait of Georgia, Rivers and Smith Inlets, and the Skeena estuary (Booth 2000; Fisheries and Oceans Canada 2000). Adults are found near shore and it is believed juveniles also remain in near shore waters. They are repeat batch spawners with females depositing their eggs on gravel beaches during summer months and producing about 20,000 eggs per season, depending on adult size (Schaefer 1936; Hart and McHugh 1944). Spawning activity has been observed and described extensively elsewhere (Schaefer 1936; Thompson *et al.* 1936; Loosanoff 1937; Yap-Chiongco 1941) and is related to both tidal and lunar cycles (Levy 1985). The rising tide assists in burying fertilized eggs in substrates of the upper tidal zone. Embryo development depends on temperature and spawning time, but larvae generally hatch after 11 days when approximately 3 mm long. Most schools are dominated by 2 year old fish (males ~138 mm and females ~ 146 mm) and adults live 4-5 years (Therriault *et al.* 2002b; Fisheries and Oceans Canada 2003b).

There is a long history of First Nations' usage of surf smelt throughout the Pacific Coast. In addition, commercial fisheries have operated in BC since the mid-1800s. There was little demand to export these small fish so catches were primarily for personal consumption or local markets. Over time, commercial landings decreased significantly, likely reflecting lack of demand, low biomass, or a shift from commercial to recreational harvests. Current catch allowances are intended for personal consumption regardless of whether the harvest is by commercial or recreational license. Detailed fisheries information is compiled in Therriault *et al.* (2002b). The surf smelt fishery is also managed by IFMP and currently there are no fishery openings in the PNCIMA area.

Most of the surf smelt fishery in the south occurs in Burrard Inlet and this area is closed seasonally from June 15 to August 15 during the spawning season.

Since little is known about factors that affect surf smelt biomass and distribution in BC, it is difficult to forecast future stock trends. A collaborative use policy has been adopted between government and industry to fund assessments for commercial fisheries. Future assessments will depend on commercial interests and should develop following a "phased approach" currently endorsed for new and developing fisheries. A number of data deficiencies have been identified for surf smelt in BC (Therriault *et al.* 2002b) and should be a priority for future research, including information on distribution, spawning biomass, fishing and natural mortality rates, and the impact of commercial and recreational fishery gear, including associated bycatch (*e.g.*, salmon, perch).

Surf smelt are indiscriminate feeders, eating a variety of zooplankton and zoobenthos including copepods, amphipods, crabs, euphausiids, larvae, marine worms, comb jellies, and a variety of larval fish (Hart 1973). In turn, surf smelt are important prey for larger predatory fish (salmon), marine mammals (harbour seals), and birds (ducks, blue herons, and bald eagles) (Pentilla 1995).

8.0 PACIFIC SARDINE

Sardinops sagax (Jenyns 1842)

Pacific sardine (*Sardinops sagax*) were commonly referred to as 'pilchard' in Canada during the peak of the fishery in the early 1900s. It is one of the most abundant species in the northeast Pacific, distributed from Baja California to southeast Alaska (Schweigert 1988). Pacific sardine spawn off Baja and southern California and migrate northward to feed. Historically, sardine migrated regularly in summer to the west coast of Vancouver Island, south of Brooks Peninsula, less frequently in or off Quatsino Sound, and infrequently in the central and northern parts of the coast (Hart 1973). With the dramatic collapse of the population in the 1940s, the range of the species contracted and they disappeared from BC waters by 1947, not reappearing until 1992 (Hargreaves *et al.* 1994). Uncertainty remains about whether sardine successfully spawn in Canadian waters (Schweigert 1988). However, during the 1997-98 El Niño, sardine eggs and one-year-old juveniles were sampled off the west coast of Vancouver Island. During this warm period, adult sardine were distributed along the entire Canadian coast, extending northward as far as southeast Alaska (McFarlane and Beamish 2001). Sardine are known to spawn regularly off the mouth of the Columbia River (Bentley *et al.* 1996). Analysis of sediment cores from the California coast indicates fairly regular 60 year cycles of sardine expansions and contractions over the last 1700 years (Baumgartner *et al.* 1992; McFarlane and Beamish 2001; DFO 2002). Rodriguez-Sanchez *et al.* (2002) found that variation in the abundance and distribution of sardine appears to be directly related to environmental variability, but there is also complex interaction with the northern anchovy (*Engraulis mordax*).

Sardine are not readily differentiated from Pacific herring, with whom they frequently school. Sardine are characterized by metallic blue or green body, with shading to silver sides, and black spots in a wide variety of sizes and patterns on the dorsal surface. Sardine also have striae on the gill covers and scale-like appendages at the caudal peduncle (Hart 1973). Young sardines are typically found in large schools inshore near beaches, whereas adults are more common offshore. Temperature limits of sardine schools in California range from 7-28 °C (Hart 1973). Spawning occurs from January to June, with the majority occurring in April and May. Spawning temperature ranges between 13 and 22 °C. Approximately half of the fish are mature at 21.5 cm; with essentially all mature at 24 cm. Females produce several batches of eggs with fecundity ranging from 30,000-65,000 eggs (the largest individuals producing about 200,000 in a season). Spawning occurs early in the night, with most of the eggs remaining in the upper (50 m) water layer. Eggs hatch in two to four days at ambient water temperature (14-16 °C), releasing 3 mm larvae. Young fish resemble adults by the time they reach 2.5 cm in length. At maximum age of 10-12 years, fish are about 31 cm long (Schweigert 1988). Females grow faster than males, with a wide variation in growth rates. After their second year, sardine migrate north in early summer, and return south in the autumn. Each year, the distances traveled in these migrations increases, eventually reaching as far north as the west coast of Vancouver Island, and often into the central coast. During very warm years, such as the 1997-98 El Niño and 2005, sardine have been found as far north as southeastern Alaska.

Sardines have been a major component of the fisheries and economies of North America during the first half of the 20th century until their collapse and disappearance in the 1940s (Figure H.6). The sardine fisheries of the mid-1920s to mid-1940s constituted the largest fishery in BC, and were in fact the largest commercial fishery in the Western Hemisphere during the first half of the 20th century (Hargreaves *et al.* 1994; Wolf 1992). The reduction fishery for sardine in BC began in 1917-18 with 70 tonnes landed and by 1926-27 the 44,000 tonne level was surpassed. An average of 40,000 tonnes was sustained for the next two decades until 1947-48 when only 444 tonnes were harvested (Schweigert 1988). Sardine was listed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) as a species of special concern in 1987. Following the 1992 return of sardines to the BC coast, an experimental fishery was initiated in 1995. With the delisting by COSEWIC in 2002, a commercial fishery was reinstituted. Harvests to date have been small, reaching a maximum of about 4300 tonnes in 2004.

The abundance of the Pacific sardine population is assessed annually by the United States using a catch-age model and estimated egg deposition from egg and larval surveys. The population is currently estimated at about 1 million tonnes, approaching levels observed early in the last century (Hill *et al.* 2005). As for other short-lived pelagic species, oceanic conditions can greatly influence sardine survival and recruitment during the early juvenile stages. Sardine survival and productivity are directly related to ocean temperatures off southern California (Conser *et al.* 2003). Marine conditions off California have been favourable in recent years, supporting the continued recovery and expansion of the population (Figure H.7).

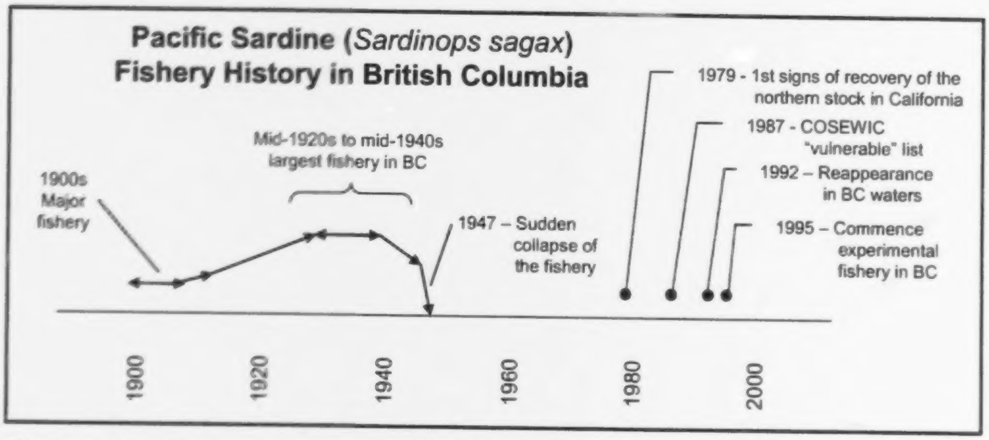


Figure H.6 The past century of the Pacific sardine fishery and notable events along the way (dates compiled from Booth 2000; McFarlane and Beamish 2001).

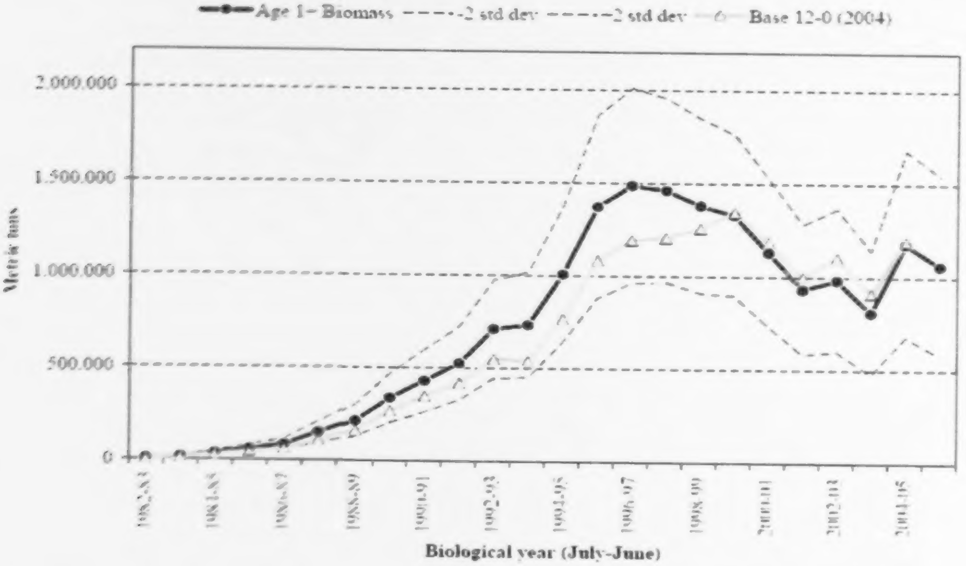


Figure H.7 Pacific sardine stock (ages 1+) biomass estimates (solid circles) along with a 2-standard deviation uncertainty envelope (dashed lines). Biomass estimates from the previous model (triangles, Base 12-0 2004) are also shown (from Hill *et al.* 2005).

During periods of abundance sardine is a very important component of the California Current ecosystem. Young Pacific sardine feed extensively on copepods and switch to diatoms as they mature (Hart 1938; 1973; McFarlane and Beamish 2001). Ahlstrom (1960) and McFarlane *et al.* (2005) noted that sardine are opportunistic, consuming fish larvae and other zooplankton when available. Sardine are prey to a wide variety of predators including commercially important fish species, seabirds, and marine mammals (Bargmann 1998; Ahlstrom 1960). Culley (1971) reports that sardines are prey for tunas, yellowtail, barracuda, bonito, marlin, hake, mackerel, sharks, and seabirds (pelicans, gulls, cormorants). McFarlane *et al.* (2005) found sardine in stomach contents of chinook and coho salmon, Pacific hake, sablefish, dogfish, and soupfin and blue shark. Humpback whales, white-sided dolphins, Dall's porpoise, and sea lions are also known to target sardine as prey. Brown pelicans have been reported to target sardine off the west coast of Vancouver Island.

It has been estimated that about 10% of the sardine population migrates into Canadian waters each year (Ware 1999), a portion of which may penetrate into the PNCIMA area. Tagging studies from the 1930s indicate that sardine annually migrate southward to spawning grounds each fall; however, there are occasional reports of Pacific sardine over-wintering in BC inlets, rather than migrating southward. A number of mass mortalities of sardine have been reported in these areas, both historically and recently (Schweigert 1988; DFO 2002). Historical descriptions of these massive die-offs are similar to recent observations on the west coast of the Queen Charlotte Islands and Douglas Channel, where sardine have succumbed to VHSV (viral hemorrhagic septicaemia virus). The mortality events indicate that sardines have attempted to over-winter as far north as Smith Inlet following the exceptionally warm El Niño summer of 1997 (Ware 1999) and even further north in 2005. While the proximal cause of death was probably VHSV infection, it is likely that increased stress levels, resulting from declining water temperatures and limited food, triggered the disease outbreak. The localized nature of sardine die-offs does not appear to pose a threat to the population as a whole and can provide periodic infusions of high energy food into the local ecosystem.

9.0 NORTHERN ANCHOVY

Engraulis mordax (Girard 1954)

Northern anchovy is a small pelagic schooling marine fish distributed from Baja Mexico to central BC. Three stocks are recognized, southern, central, and northern, with the latter ranging into BC. Northern anchovy are typically found in the upper mixed and surface layers of the continental shelf and adjacent deep-water regions (Hart 1973). Mature and immature fish remain inshore during fall and winter months while the adults move offshore during summer months (Laroche and Richardson 1980).

Northern anchovy have an elongate body with a head that is characterized by a short snout and a large protruding lower jaw enabling the mouth to open widely to strain water through the gills. Coloration varies from blue to green on the dorsal surface and silvery to white on the side and belly. Maximum length for northern anchovy in BC is approximately 168 mm for females at 7 years and 153 mm for males at 6 years, but northern anchovy are typically 120-140 mm averaging 3-4 years old (Pike 1951; Miller 1955). Anchovy captured in BC are slightly smaller at age than the more southerly populations (Parrish *et al.* 1985).

Anchovy school for reproduction, migration, feeding, and predator avoidance beginning at an early larval stage (11-12 mm) (Hunter and Coyne 1982). Spawning may occur in southern BC but is not well documented. Outside of BC, the northern stock spawns during summer months while the two southerly stocks spawn primarily in late winter or all year around (Vrooman *et al.* 1981) and the preferred water temperature for spawning is 13-18 °C. Spawning usually occurs within 100 km of the coast where eggs and milt are released into open water, generally in the upper 30 m of the water column (Moser and Pommeranz 1999). The eggs are pelagic, typically ovoid and 1.23-1.55 mm in length, hatching into 3 mm larvae after 2-4 days depending on temperature (Richardson 1981). Egg buoyancy decreases as embryonic development progresses and after hatching, the larvae are pelagic and spend most of their first year in the surface currents (McHugh 1981). Anchovy begin to resemble the adult form when they are approximately 25 mm in length and develop scales by the time they reach 41 mm.

Catch records and research data indicate that anchovy occur at low densities in bays and inlets of southern BC with recent northern occurrences reported near Fitz Hugh Sound in the central coast of BC (Therriault *et al.* 2002a) but historic observations indicate distribution ranging to near the Queen Charlotte Islands (Roach and Harrison 1948; McHugh and Fitch 1951; Hart 1973). A small seine fishery, mainly for bait, intermittently operated historically on the west coast of Vancouver Island since the 1930s. Various marketing strategies for the anchovy occurred through the 1940s, but most were unsuccessful. The lack of fish and markets resulted in the closure of the commercial fishery in BC in 2003.

Northern anchovy are daytime filter feeders, feeding indiscriminately on prey of suitable size rather than selecting specific prey species (Koslow 1981; as cited in Therriault *et al.* 2002a). Anchovy larvae feed primarily on copepods (Booman *et al.* 1991) while adult prey items include planktonic crustaceans, and fish eggs and larvae (Baxter 1967; Hunter and Kimbrell 1980). Anchovy are an important food source for piscivorous fish such as tuna, shark, chinook and coho salmon, as well as marine mammals and birds (Olesiuk *et al.* 1990; Emmett *et al.* 2001). In the southern stocks, the breeding success of California brown pelicans and elegant terns has been strongly correlated with anchovy abundance. Historically, the abundance of anchovy and sardines in the California Current system was inversely related but it is unclear whether the relationship continues to apply (Rodriguez-Sanchez *et al.* 2002; Baumgartner *et al.* 1992; Fisheries and Oceans Canada 2003a, and others). During periods of high abundance, either sardine or anchovy can be an important prey item.

10.0 AMERICAN SHAD

Alosa sapidissima (Wilson 1811)

American shad (*Alosa sapidissima*) was introduced from the Atlantic coast to the Sacramento River in California in the early 1870s (Hart 1973) and has spread rapidly throughout the Pacific. It is found from Kamchatka, Russia through Alaska and as far south as northern Baja Mexico. It ranges from the surface to depths of 250-375 m. In BC, shad have been captured incidentally in offshore trawl and seine gear. There are no directed commercial fisheries. Recently, shad have been captured by mid-water trawlers in significant quantities (several thousand pounds) as bycatch in the Pacific hake fishery off the lower west coast of Vancouver Island and in Juan de Fuca Strait (Venables 2005). Shad are rarely captured in the Fraser River or any other BC river. It is likely that many shad in southern BC waters originate from the Columbia River where a significant spawning population resides. Reports in the PNCIMA area are more sporadic, such as incidental catches in Queen Charlotte Sound and Central Coast inlets (*e.g.*, Rivers Inlet).

Adult shad range in size from 30-60 cm and 1-3 kg. In appearance, they have a broad, laterally compressed body similar to Pacific herring. Shad are distinguished by a deeper body and a single row of dark spots (3-23) along the side and saw-tooth scales or "scutes" along the abdomen (Hart 1973). Shad are anadromous but little is known of their life history in BC waters.

On the Atlantic coast, shad spawn in deep, swift areas of rivers and females release an average of 130,000 eggs annually, each measuring 2.5-3.5 mm in diameter. Fertilized eggs are non-adhesive and are carried downstream by the current. Hatching occurs quickly in 1-2 weeks, depending on river temperature (12-20 °C). Unlike eulachon, shad larvae are reared within the river and post-spawning adults rejoin the ocean migratory population. After hatching at approximately 10 mm in length, juvenile shad spend their first summer feeding in the river or estuary and then migrate offshore in autumn when river temperatures drop below 15 °C (Hart 1973). Shad mature at 4-5 years of age and, among Canadian populations, may spawn up to seven times and live up to 13 years. Adults feed mostly on copepods, mysids, euphausiids, and small fish. They are prey for sharks, tuna, sea lions, and other piscivores such as cod and dogfish. Shad are popular recreational fish and are prized for their roe. Due to their limited abundance within PNCIMA, it is unlikely that they will play a significant role in the ecosystem. The major threat to their populations has come from barriers to upstream migration such as dams or waterfalls.

11.0 ALBACORE TUNA

Thunnus alalunga (Bonnaterre 1788)

Albacore tuna (*Thunnus alalunga*) is a highly migratory pelagic species found in the Atlantic, Pacific, and Indian Oceans. In the eastern Pacific, albacore tuna range from Prince William Sound, Alaska to Chile. As sea surface temperatures rise, tuna migrate northward as much as 11 km per day, following the warm water. Migrating albacore concentrate along thermal discontinuities (ocean fronts) associated with waters of the Transition Zone in the North Pacific Ocean. Most albacore are caught in waters with a sea surface temperature ranging from 15-19 °C (Crone 2003). During the summer months, typically July and August, albacore appear erratically along the offshore coasts of BC (Hart 1973). Strong climatic changes, such as those caused by El Niño events, dramatically influence the feeding distribution of albacore tuna. The presence of tuna within the PNCIMA region is rare but could increase with increasing sea surface temperature associated with global warming.

Reproduction occurs in the spring, January to June, generally in the western part of the range from Japan to Hawaii. Juvenile albacore grow rapidly about 4 cm per month, and reach roughly 3 kg in their first year. Subsequent growth is 7-13 cm per year. They mature at 5-6 years of age, and can be 89-104 cm long and weigh an average of 16-24 kg. The maximum fork length is about 135 cm, averaging 125 cm. Off the Canadian coast, mature albacore rarely exceed 98 cm, averaging about 90 cm total length (Hart 1973). Ageing is difficult, but albacore are believed to reach a maximum age of 11-12 years (Crone 2003).

The Pacific-wide albacore tuna fishing effort is multi-national. Fishing fleets follow this highly migratory quarry as the waters and food sources dictate its feeding migrations. Canadian fishers have been pursuing albacore since the mid-1930s in the North Pacific, and recently (1980s) in the South Pacific. The North Pacific fishery lasts from May through October, and the South Pacific fishery runs from December through March. The Canadian fleet of smaller inshore fishing vessels range from the southern Oregon coast to the northern tip of Vancouver Island (Fisheries and Oceans Canada 2002c; Hart 1973). Since the 1950s, the total Pacific-wide albacore catches have ranged from 70,000-150,000 tonnes per year. Canada recently joined the Western and Central Pacific Fisheries Commission (WCPFC) which has responsibility for management of the albacore resource.

Albacore, like other tunas, lack the physical structures necessary to pump water over their gills to obtain oxygen. As a result, their respiration requires constant swimming, and combined with their ability to swim at high speeds, allows them to cover vast areas during their annual migration (Crone 2003). In order to sustain their physically demanding habits they have a high metabolic rate and require large quantities of food, at times consuming as much as 25% of their body weight each day. Albacore diet consists of sardines, herring, anchovy, myctophids, saury, small rockfish, squid and euphausiids. In addition to man, their predators may include blue marlin, striped marlin, wahoo, and larger species of billfish, tuna, and sharks (Fisheries and Oceans Canada 2002b; Crone 2003).

12.0 NORTHERN SMOOTHTONGUE

Leuroglossus schmidti (Rass 1955)

The northern smoothtongue belongs to the family Bathylagidae or deepsea smelts. The species occurs from southeastern Hokkaido to the Bering Sea on the Asian coast and south to southern Vancouver Island on the North American coast. The smoothtongue is a mesopelagic species that has been reported to depths of 1800 m, normally occurring to about 700 m but also observed at the surface. Night time diel migration patterns to the surface are observed in most areas and daytime occurrence has been observed in near shore surface waters of glacially turbid fjords (Abookire *et al.* 2002). Adults are observed infrequently, usually at night, from mid-water trawling with fine-mesh trawl liners or dropping from trawl meshes as nets break the surface. Smoothtongue often coexists with adult Pacific hake (*Merluccius productus*) and walleye pollock (*Theragra chalcogramma*) in the Strait of Georgia and in the deeper portions of inlets and fjords in the PNCIMA region. Northern smoothtongue are characterized by low fecundity, slow growth, and a short life span. Adults may reach 15 cm but are usually less than 7 cm in length, mature at 2 years of age, and live for 4-6 years (Mason and Phillips 1985).

Absolute abundance of smoothtongue is difficult to assess. In the Sea of Okhotsk off Russia, northern smoothtongue are relatively abundant, comprising 42-66% of the mesopelagic biomass (Dulepova and Radchenko 2003). During ichthyoplankton surveys (conducted at 0-20 m depth) in the central coastal inlets of PNCIMA, the northern smoothtongue larvae ranked third in abundance behind Pacific herring and eulachon (McCarter and Hay 1999). Surveys were conducted between April and June and larvae were found concentrated in surface waters (0-20 m) whenever bottom depths exceeded 400 metres, inside of most inlet sills and always within estuarine inlet circulation. Mason and Phillips (1985) encountered similar concentrations at slightly deeper depths in the Strait of Georgia basin during egg and larval surveys for Pacific hake and pollock.

Bathylagids have a small mouth, dense flat gill rakers, a small stomach and long intestine. They consume weak swimming soft-bodied animals such as pteropods, appendicularia, ctenophores, chaetognaths, polychaetes, and jellyfish. Bathylagids in the epipelagic zone can also feed on euphausiids and copepods at night when they are abundant (Gorelova and Kobylyanskiy 1985; Balanov *et al.* 1995). Seabirds nocturnally feed on abundant deepsea smelt (Abookire *et al.* 2002) and northern smoothtongues have been identified in the stomachs of herring, eulachon, sand lance, and chinook salmon (Hart 1973), and at times are an important food for fur seals. The mesopelagic distribution of this deepsea smelt species results in some predator avoidance, but seasonal trophic roles within the PNCIMA ecosystem remain unclear. Because of their relatively small size and depth distribution, it is difficult to assess the abundance and importance of bathylagids in the PNCIMA ecosystem.

13.0 SUMMARY

Most of the pelagic species discussed in this chapter are numerically abundant, schooling, migratory fishes that are relatively short-lived. Therefore, they are prone to dramatic natural fluctuations in population abundance, usually as a result of variations in environmental conditions that affect their survival. Pelagic species are the glue that holds the ecosystem together since they are a favoured and critical prey for many species at higher trophic levels. Pelagic species normally feed on plankton at lower trophic levels and consequently are usually high in lipid content.

The pelagic species as a group also have evolved a spawning modality that favours depositing their eggs and young in the inshore or in-river environment to minimize predation from abundant offshore predator populations. As a consequence, pelagic forage species are highly susceptible to anthropomorphic impacts on the nearshore environment from a variety of sources. Recognizing and mitigating these effects will be critical to the sustainability of many of the pelagic species and the long-term health of the PNCIMA and other ecosystems.

14.0 USEFUL INTERNET RESOURCES

Pacific fisheries management pelagic fish web page:
http://www.pac.dfo-mpo.gc.ca/ops/fm/herring/default_e.htm

Pacific science pelagic fish web page:
http://www.pac.dfo-mpo.gc.ca/sci/herring/default_e.htm

DFO Canadian Science Advisory Secretariat Research Documents:
http://www.dfo-mpo.gc.ca/CSAS/csas/publications/Pub_index_e.htm

DFO Science Stock Status Reports – pelagic fish:
http://www.pac.dfo-mpo.gc.ca/sci/psarc/SSRS/pelagic_ssrs_e.htm

Aboriginal fisheries:
http://www.pac.dfo-mpo.gc.ca/tapd/Default_e.htm

Pacific fisheries management consultations – Pelagic species:
http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/consultations/pelagics/default_e.htm

Integrated Fisheries Management Plans (IFMP) – all species:
http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/mplans/mplans.htm

Committee on the Status of Endangered Wildlife in Canada (COSEWIC):
http://www.cosewic.gc.ca/eng/sct5/index_e.cfm

BC Tidal Waters Sport Fishing Guide:
http://www.pac.dfo-mpo.gc.ca/recfish/default_e.htm

Sea Surface temperatures Pacific Region web page:
http://www.pac.dfo-mpo.gc.ca/sci/osap/data/sstarchive_e.htm#

Robards, M.D. *et al*. reviews of all six recognized species of sand lance:
http://www.fs.fed.us/pnw/pubs/rp_521.htm

Herring spawn and harvest information:
http://www.pac.dfo-mpo.gc.ca/sci/herring/herspawn/pages/default3_e.htm

Environment Canada - National set of indicators – Pacific herring:
http://www.ec.gc.ca/soer-ree/English/Indicators/Issues/Herring/Bulletin/ph_iss_e.cfm?accessible=on

Proceedings of the Sardine Symposium, 2000:
http://nsgl.gso.uri.edu/cuimr/cuimrw00001/cuimrw00001index.html

British Columbia Tuna Fisherman's Association:
http://www.bctfa.com/

Albacore Biology/Ecology:
http://swfsc.nmfs.noaa.gov/frd/HMS/Large%20Pelagics/Albacore/albie01.htm

15.0 GLOSSARY

Anadromous – Refers to species of fish that spawn in freshwater but live most of their lives in saltwater, returning to freshwater to spawn.

Estuary – An inlet or arm of the sea; especially the wide mouth of a river, where the tide meets the current.

Fecundity – The reproductive capacity of an individual or a population, generally measured by the number of eggs produced.

Metamorphosis – Refers to the change in the shape or form of an individual, usually associated with the conversion that takes place from the larval to juvenile phase in fishes.

Piscivorous – A species of fish that feeds primarily on other fishes.

Semelparous – Refers to a species of fish where the individuals all die soon after spawning.

Viviparous – Refers to a method of reproduction where the embryo develops within the female and from whom it receives nourishment. The female gives birth to highly developed, free-swimming offspring.

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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX I: PACIFIC SALMON

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1.0 INTRODUCTION

1.1 General Biology and Importance

Pacific salmon (genus *Oncorhynchus*) are an important biological, cultural, and economic resource of countries of the North Pacific rim. The range of salmon extends from southern California, north along the Canadian and Alaskan coasts to rivers draining into the Arctic Ocean, and then southward along Asian coastal areas of Russia, Japan, and Korea (Groot and Margolis 1991). There are 8 species of Pacific salmon 6 of which (*i.e.*, sockeye, pink, chum, chinook, coho, and steelhead salmon) are commonly found on the west coast of North America. The fossil record suggests that ancestral Pacific salmon have been around for at least 18 million years and the several distinctive species we recognize today have been around for at least 6 million years (Augerot *et al.* 2005).

At the most general level, all Pacific salmon exhibit similar life cycles: they spawn in gravel beds in rivers, streams or along lake shores. They generally migrate to sea as juvenile forms after a period of freshwater life varying from days to years (Figure I.0); an additional period of several months to years is usually spent at sea feeding and rearing to the adult stage. Salmon are widely distributed over the North Pacific Ocean and Bering Sea during the marine phase of their life history (Hartt and Dell 1986). Populations or sub-populations of some species may remain in fresh water (*e.g.*, the freshwater form of sockeye salmon known as kokanee) or stay in coastal waters (many chinook and coho populations) but most engage in extensive migrations while at sea. In the Pacific, salmon usually return to their home rivers and natal breeding grounds to spawn and then die, except for steelhead salmon (*O. mykiss*) which may spawn repeatedly (Augerot *et al.* 2005). Although there are only 6 species of wild Pacific salmon in British Columbia (BC), high levels of habitat diversity and variable environmental conditions have combined with a strong tendency for salmon to "home" to their rivers of origin, promoting the rapid, postglacial, evolution of many thousands of salmon populations specifically adapted to local conditions (Riddell 1993). All six species of North American salmon are currently common in freshwater and marine ecosystems of the Pacific North Coast Integrated Management Area (PNCIMA) bounded by British Columbia's North and Central Coast (Figure I.1).

Although salmon undoubtedly occupied North America in the absence of human populations for millennia, human migration and settlement of North America, including PNCIMA, around the end of the last glacial retreat (12,000 yrs B.P.) initiated economic, cultural and ecological interactions between humans and salmon that have been maintained for thousands of years. Wild salmon serve as a vital source of food for First Nations people (Stewart 1977) and have played a central and now constitutionally protected role (Fisheries and Oceans Canada 2005; 2006) in the development of their rich culture and spirituality (Drucker 1963). Pacific salmon have also continued to play important roles in the historical, economic, and cultural development of recent generations of all Canadians living in British Columbia by providing jobs, income, and enjoyment for individuals, businesses, and communities (Fisheries and Oceans Canada 2005). In addition, thousands of populations of salmon continue to play key roles in natural ecosystems, nourishing a complex web of interconnected species distributed from the furthest reaches of the North Pacific Ocean to the headwaters of mountain streams throughout countries bordering the North Pacific Rim (Cedarholm *et al.* 2000; Stockner 2003; Naiman and Latterell 2005).

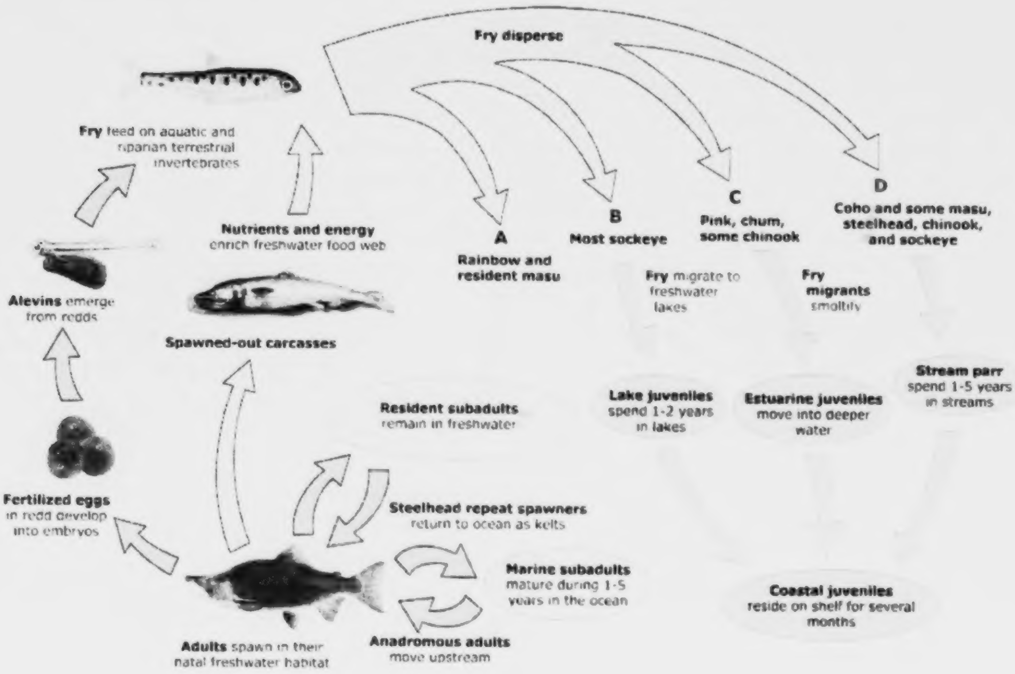

Fry disperse
Fry feed on aquatic and riparian terrestrial invertebrates
Nutrients and energy enrich freshwater food web
Alevins emerge from redds
Spawned-out carcasses
Fertilized eggs in redd develop into embryos
Resident subadults remain in freshwater
Steelhead repeat spawners return to ocean as kelts
Marine subadults mature during 1-5 years in the ocean
Adults spawn in their natal freshwater habitat
Anadromous adults move upstream
A
Rainbow and resident masu
B
Most sockeye
C
Pink, chum, some chinook
D
Coho and some masu, steelhead, chinook, and sockeye
Fry migrate to freshwater lakes
Fry migrants smoltify
Lake juveniles spend 1-2 years in lakes
Estuarine juveniles move into deeper water
Stream parr spend 1-5 years in streams
Coastal juveniles reside on shelf for several months

Figure I.0 General overview of Pacific salmon (Genus *Oncorhynchus*) life history patterns (adapted from Augerot *et al.* 2005).

1.2 Status and Trends of Salmon in PNCIMA

PNCIMA is an important migration corridor, marine rearing, and staging area for salmon migrating seaward as juveniles and then returning as adults to their coastal watersheds of origin. PNCIMA is occupied for a variable period of time not only by the majority of salmon stocks originating from British Columbia but also by many populations originating from the states of Washington, Oregon, and even California. The variable nature of their spatial and temporal associations within PNCIMA suggests that salmon may be considered in three classes including (1) resident in and originating from PNCIMA, (2) resident in but originating from outside PNCIMA, or (3) transients passing quickly through PNCIMA. Although PNCIMA is undoubtedly important to all three

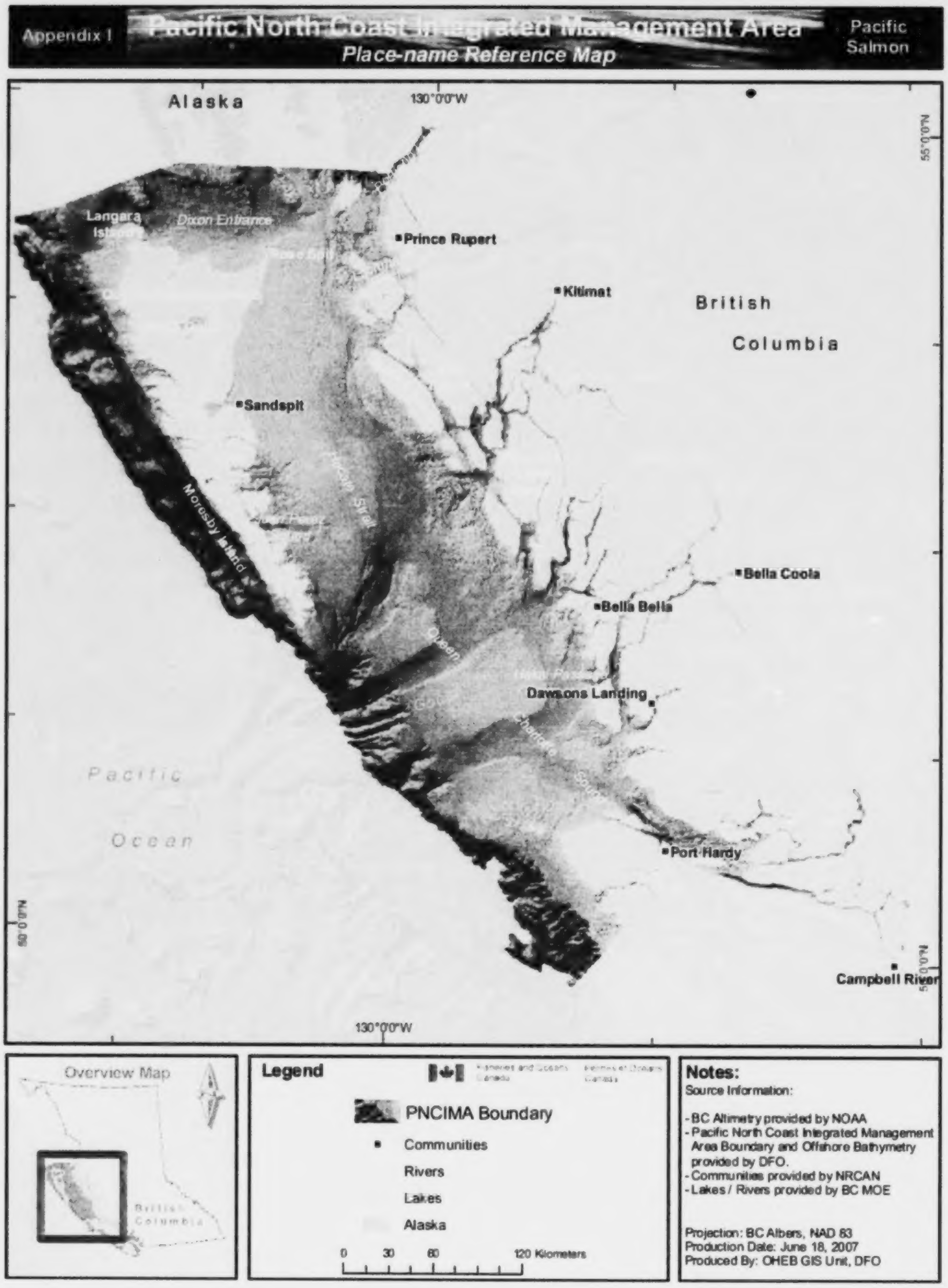

Appendix I
Pacific North Coast Integrated Management Area
Place-name Reference Map
Pacific Salmon
Alaska
130°0'0"W
55°0'0"N
Langara Island
Dixon Entrance
Prince Rupert
Kitimat
British Columbia
Sandspit
Moresby Island
Hecate Strait
Bella Coola
Bella Bella
Dawsons Landing
Pacific Ocean
Port Hardy
50°0'0"N
Campbell River
Overview Map
British Columbia
Legend
Fisheries and Oceans Canada
PNCIMA Boundary
Communities
Rivers
Lakes
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure I.1 PNCIMA region showing locations and features of BC waters.

groups, the focus of information presented here on status and trends is largely restricted to those populations in class (1).

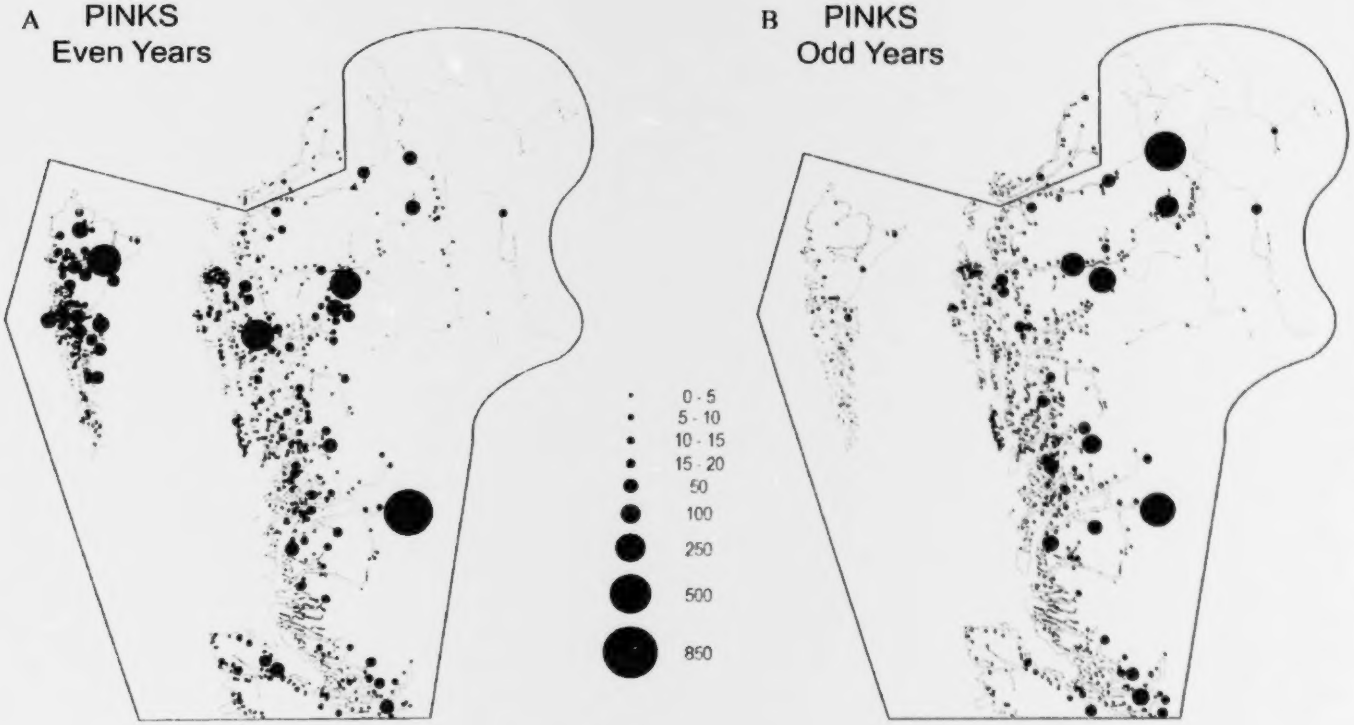
1.2.1 Status

Aro and Shepard (1967) compiled the first extensive synthesis of the status of populations of Pacific salmon spawning in Canada, including PNCIMA. They ranked the main spawning streams for each species in order of their average abundance during the years 1951-1962 and summarized a wide range of information for all "major" populations. Major populations were defined as those achieving escapements on two or more occasions above a set value for each species (*i.e.*, >5000 sockeye, >20,000 pinks, >10,000 chums, >2000 coho, and >500 chinook salmon) within the subject interval. Results suggested PNCIMA hosts approximately 383 major populations of 5 species of Pacific salmon including: 131 pink (58 odd-year, 64 even-year), 94 coho, 67 chum, 55 sockeye, and 36 chinook populations.

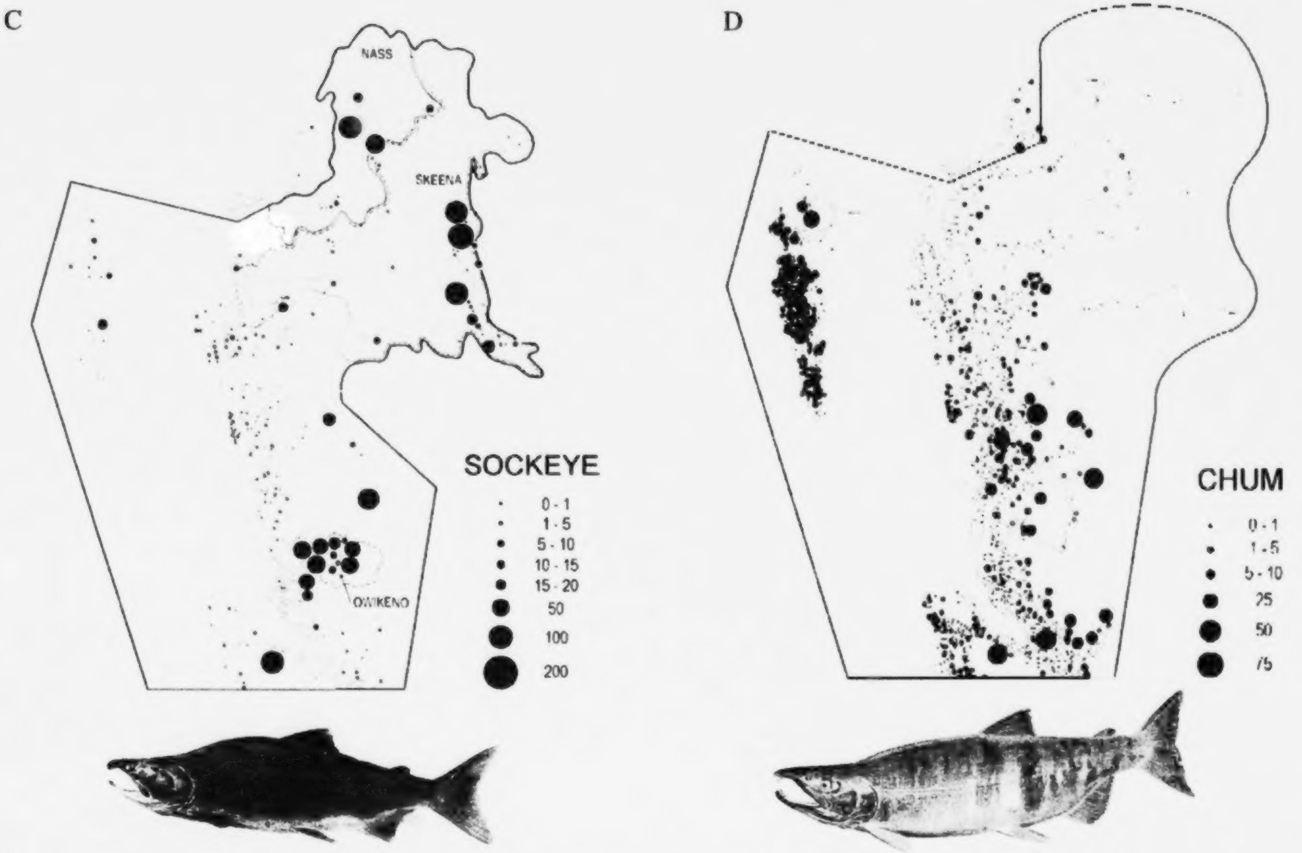
Pinks are the numerically dominant species of salmon in PNCIMA (mean total escapement >5 million adults). Pink salmon populations are distributed broadly throughout PNCIMA (Figure I.2a, 2b) but the majority of pink salmon production is associated with a few large populations (>250,000 spawners) returning to major river systems such as the Bella Coola-Atnarko (S-PNCIMA), the Kitimat (N-PNCIMA), the Yakoun (Queen Charlotte portion of PNCIMA) and the Skeena (NE-PNCIMA). Odd and even-year lines of pink salmon are well represented in rivers throughout PNCIMA except for Queen Charlotte Islands populations where even-year pinks (Figure I.2a) exhibit higher abundance and a broader distribution than odd-year pinks (Figure I.2b). In aggregate, chum is the second most abundant species of salmon in PNCIMA with local populations commonly exceeding 25,000 adults (Figure I.2d). The distribution of chum salmon populations is similar to that of even-year pink salmon including an especially high utilization of rivers on the Queen Charlotte Islands (QCI). On the mainland, the largest populations of chum are clustered in and around inlets tributary to Johnstone Strait and in areas immediately north of Dean Channel. Sockeye salmon populations are third in aggregate abundance, broadly distributed throughout coastal and interior watersheds of PNCIMA. However, populations originating from a few large lakes in the Nass (Meziadin and Bowser lakes), Skeena (Babine Lake), Nimpkish (Nimpkish and Woss lakes) and Rivers Inlet (Owikeno and Long lakes) areas of PNCIMA account for greater than 90% of average annual abundance (Figure I.2c) on the order of 1-3 million spawners. By contrast, scores of small populations containing fewer than 5,000 spawning adults account for less than 10% of the total escapement of sockeye to PNCIMA.

Among the 5 species of salmon considered by Aro and Shepard (1967), coho exhibited the widest and most equitable numeric distribution occupying not only major rivers but also small coastal streams and penetrating far into interior watersheds of PNCIMA (Figure I.2e). Most populations of spawning coho are small (<5000 spawners) with fewer than ten populations routinely containing more than 25,000 spawners (*e.g.*, Bella Coola R.). Chinook salmon were represented by the fewest populations and the lowest aggregate numbers (area wide escapement of <150,000 fish) among the 5 salmon species (excluding steelhead salmon). They exhibit highly disjunct distributions within PNCIMA (Figure I.2f) where they spawn in mainstem locations of a few large rivers often associated with the outlets of large lakes.

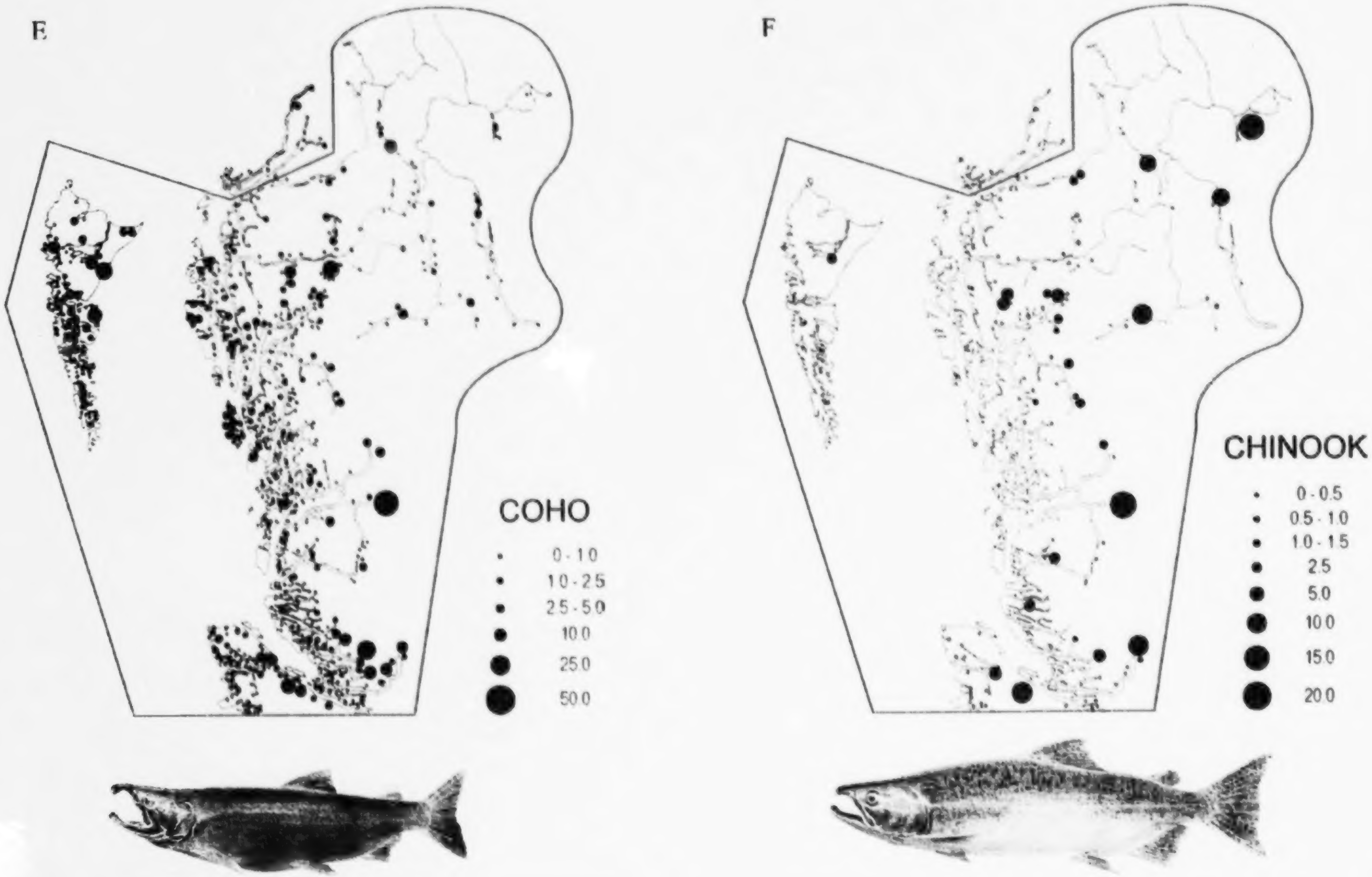
Aro and Shepard (1967) identified fewer than 400 "major" populations of 5 species of Pacific salmon in PNCIMA but clearly many of the smaller populations that contribute to the impressive biodiversity of salmon in the area were excluded from their list. A more recent review of the status of both "major" and "minor" populations of anadromous salmon and trout in British Columbia and the Yukon (Slaney *et al.* 1996) identified the existence of more than 9,000 site-specific, spawning populations among 6 species of Pacific salmon originating within Canadian waters. Hundreds of watersheds both large (*e.g.,* Nass, Skeena, etc.) and small (*e.g.,* QCI area) within PNCIMA provide critical spawning habitat for more than 5,000 spawning aggregations or approximately 58% of all anadromous salmon populations originating from Canada's west coast (Table I.1).


A
PINKS
Even Years
B
PINKS
Odd Years
0 - 5
5 - 10
10 - 15
15 - 20
50
100
250
500
850

Figures I.2a and I.2b Distribution and average abundance (1951-1962) of "major" spawning aggregations of even-year pink (a), odd-year pink (b), occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).


C
NASS
SKEENA
OWIKENO
SOCKEYE
0 - 1
1 - 5
5 - 10
10 - 15
15 - 20
50
100
200
D
CHUM
0 - 1
1 - 5
5 - 10
25
50
75

Figures I.2c and I.2d Distribution and average abundance (1951-1962) of "major" spawning aggregations of sockeye (c), chum (d), occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).


E
COHO
0 - 1.0
1.0 - 2.5
2.5 - 5.0
10.0
25.0
50.0
F
CHINOOK
0 - 0.5
0.5 - 1.0
1.0 - 1.5
2.5
5.0
10.0
15.0
20.0

Figures I.2e and I.2f Distribution and average abundance (1951-1962) of "major" spawning aggregations of coho (e) and chinook salmon (f) occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).

Table I.0 Numbers and status of resident salmon populations by species and area in PNCIMA (adapted from Table 2 of Slaney *et al.* 1996).

DFO Statistical Areas	**Extinct**	**High Risk**	**Medium Risk**	**Special Concern**	**Low Risk**	**Unknown**	**Total**	**% of all Stocks**
Nass (3B)	0	27	0	16	233	275	551	5.7
QCI (1, 2W, 2E)	0	84	6	2	557	419	1,068	11.0
Skeena (4)	2	44	1	38	432	435	952	9.8
North Coast (5)	0	41	5	0	267	271	584	6.0
Central Coast (6,7,8)	1	153	11	15	827	489	1,496	15.0
Rivers-Smith (9-11)	0	9	0	9	133	85	236	2.4
NWVI	0	43	4	9	289	336	681	7.1
PNCIMA Totals	3	401	28	89	2,738	2,310	5,568	57.6
(% of BC)	**2**	**64**	**36**	**39**	**62**	**55**	**58**	**58.0**
BC-total	142	624	78	230	4,417	4,172	9,663	100

The status of these stocks was assessed by employing a commonly used risk classification scheme (Nehlsen *et al.* 1991). Limits on quantitative information for 2,310 or 41% of PNCIMA salmon populations precluded any meaningful statement about their current status other than "status unknown". However, for the 3,259 or 59% of salmon populations that were assessed, results suggested that: 84% were healthy (*i.e.,* virtually no short term risk of biological extinction), 12% were at high risk of loss, and only 3 populations (<0.1%) were confirmed as having gone extinct within recent history (Table I.1, see Slaney *et al.* 1996 for details of risk criteria).

Riddell (2004) adopted a different classification scheme in a Pacific Fisheries Resource Conservation Council (PFRCC) review of status and trends exhibited by salmon populations in PNCIMA, which may be considered for comparative purposes. Riddell concluded that no fewer than 2,983 populations of Pacific salmon originate from watersheds of PNCIMA. Ranked in order, these included 1,120 pink, 882 coho, 610 chum, 236 sockeye and 135 chinook salmon populations. Although the rank order of abundance of populations by species was similar among all three studies considered here, the Slaney *et al.* study identified the maximum number of salmon populations in the PNCIMA area (5,568 by Slaney *et al.* versus 2,983 by Riddell versus 383 by Aro and Shepard). Further, at least one recent study has suggested an even larger number of salmon populations may reside in PNCIMA, once small streams that are seldom surveyed are accounted for (Harvey and MacDuffee 2002). Differences between studies are largely attributable to variable screening criteria and boundaries used to identify populations falling within the geographic area of interest (*e.g.,* only Slaney *et al.* considered steelhead salmon and Riddell did not include populations from Northwest Vancouver Island).

Although screening criteria and procedures differed between the studies by various authors, general conclusions regarding PNCIMA salmon population status are similar.

Thus, Riddell's detailed consideration (Table 2.2 of Riddell 2004) of 117 sockeye stocks in PNCIMA suggested that available information was insufficient to support meaningful statements on the status of 44%, while 41% of all PNCIMA salmon populations that Slaney *et al.* considered could not be assigned a known status due to information limitations. Results from both studies suggest that, overall, salmon populations within PNCIMA currently exhibit lower levels of recent extinctions and/or proportionately fewer stocks at high risk than for salmon populations originating from areas south of PNCIMA (Nehlsen *et al.* 1991; Slaney *et al.* 1996). All studies agree that quantitative information on the status of relatively large and productive salmon populations that provide most of the biomass for commercial harvest for a given species is far superior to that available for the majority of small streams. The latter may often contain less productive populations but could account for most of the genetic biodiversity contained among populations. The widespread distribution of populations regarded as exhibiting high risk (Figure I.3) and the inability to currently classify the status of hundreds of small populations of all species in PNCIMA remains an issue of concern (Thomson and MacDuffee 2002; PFRCC 2005).

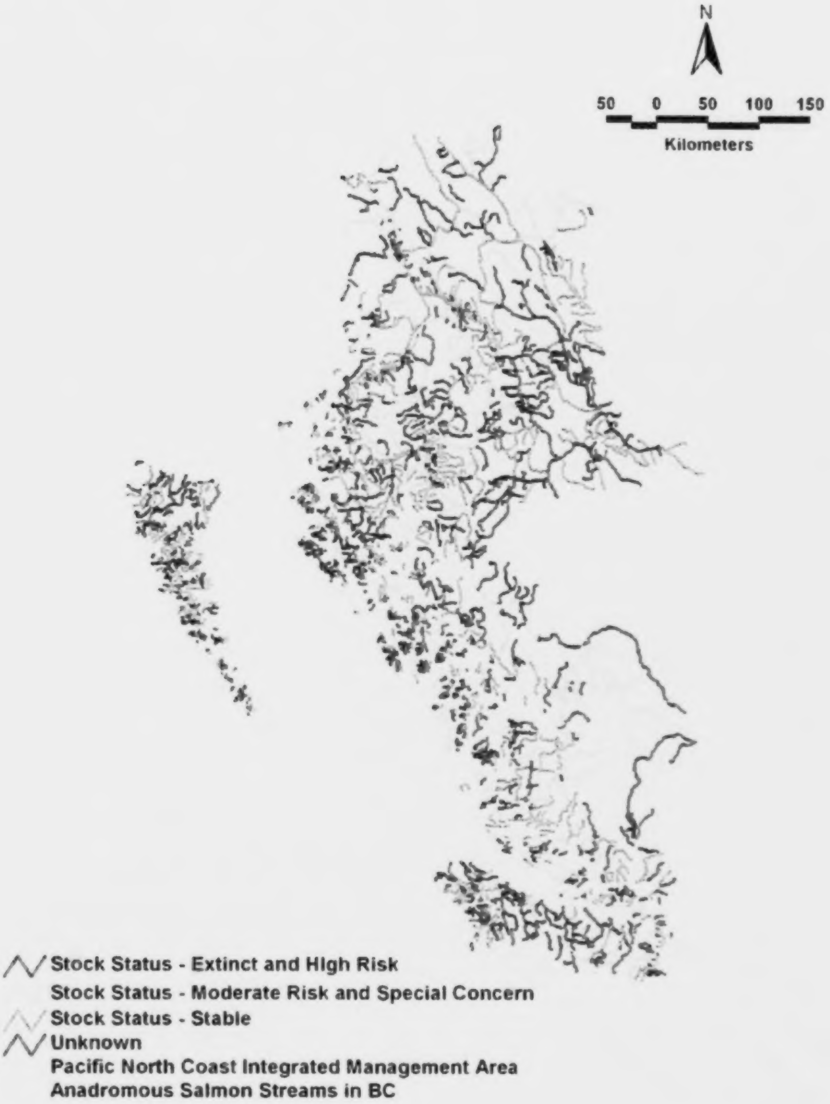

N
50 0 50 100 150
Kilometers
Stock Status - Extinct and High Risk
Stock Status - Moderate Risk and Special Concern
Stock Status - Stable
Unknown
Pacific North Coast Integrated Management Area
Anadromous Salmon Streams in BC

Figure I.3 Distribution of salmon stocks by risk category within PNCIMA as of 1993; red = high risk of extinction, amber = moderate risk or special concern, green = healthy, and blue = unknown status (adapted from Slaney *et al.* 1996).

1.2.2 Trends

Pacific salmon exhibit large fluctuations in abundance in both space and time, at levels ranging from local populations to entire species aggregates, summed within major geographic areas such as PNCIMA. Except for small areas in the Queen Charlotte Islands and possibly the northwest tip of Vancouver Island, most of PNCIMA was extensively glaciated and therefore largely devoid of salmon populations as recently as 12,000 years B.P. (McPhail and Lindsey 1986). Inferences about salmon abundance during the latter period are based on archaeological or paleoecological observations that provide insights into prehistoric change, along with stock assessment observations (*e.g.*, annual records of catch and spawning numbers) during the historic interval from the late 1800s to present.

Archeological evidence from studies of middens throughout the BC coast, including PNCIMA, indicates the presence of highly abundant salmon populations throughout the several thousand year interval of human occupation. However, archaeological observations are not sufficiently rich to use as a basis for inferences regarding numeric trends in prehistoric salmon abundance. Potentially more revealing, paleoecological investigations are underway in several PNCIMA locations (M. Pellat, Parks Canada, pers. comm., 2006) but, as yet, remain unpublished. However, published results from similar studies are relevant to inferences about potential long-term trends for salmon in PNCIMA as they confirm the occurrence of large natural variations in Pacific salmon abundance prior to the advent of industrial fishing and widespread landscape alterations associated with European settlement of the west coast. Thus, a >2000 year reconstruction of sockeye salmon abundance from analyses of lake sediment cores in Alaska (Finney *et al.* 2000; Gregory-Eaves *et al.* 2003) indicated large shifts in salmon abundance, far exceeding variations recorded there during the past 300 years. Taken in concert with other evidence, suggesting strong coherence of changes in regional fish populations (Francis *et al.* 1998; Beamish *et al.* 1999), paleoclimate results support the view that changes to ocean regimes and climate related factors alone may greatly influence salmon production patterns and abundance over centuries of time in geographic areas as large as PNCIMA.

During the recent historic period (late 1950s to present) detailed observations of spatial and temporal trends of salmon are available as records of salmon catch and spawner abundance (*i.e.*, escapement) within PNCIMA (Wong 1983; Serbic 1991; Department of Fisheries and Oceans, unpublished data). Examination of these records for salmon that utilize marine areas and that also originate from watersheds within PNCIMA suggests the following trends in total abundance among species and then within species. On average, 25-30 million adult salmon return each year to watersheds of PNCIMA. However, annual fluctuations in returns are large, ranging from 12 to 48 million adults, and the clear dominance of even-year pink numbers on total return patterns is evident throughout the time series (Figure I.4). At a gross level, catch and escapement observations reflect similar trends, where alternating periods of relatively low and then high production of salmon are evident in both catch and escapement records during the 1950s versus 1960s and then during the 1970s versus 1980s respectively. Total returns of salmon to

PNCIMA have declined to well below the all-year average during the most recent decade (1997-2006). Because of their numeric dominance in PNCIMA, pink, chum and sockeye salmon aggregates exhibit few departures from the all-species pattern just described (Figures I.4b, I.4c, and I.4d). Notable exceptions to this are the spectacular collapse of two major populations of sockeye salmon at Rivers Inlet (Owikeno Lake) and Smith Inlet (Long Lake) that, in aggregate, produced average annual returns in excess of 1.3 million salmon for the entire period from 1950-1993 but then declined sharply thereafter to minimum single year returns reported at less than 10,000 adults and multiyear returns averaging less than 100,000 adults (Riddell 2004). McKinnell *et al.* (2001) provided evidence that the collapse of these neighboring sockeye stocks within PNCIMA was attributable to as yet unknown events that influenced survival during the marine portion of their life history.

Chinook salmon production in PNCIMA has exhibited relatively little variation (Figure I.4e) averaging roughly: 300,000 during the 1950s, increasing to roughly 400,000-500,000 during the 1965-1995 interval and then dropping below average returns of 300,000 adults after 1998. Coho salmon production trends contrast with that of other species in that total returns appear to be on the order of 1.9 million during the 1950-1970 interval, 1.5 million during the 1970-1990 interval and then averaging less than 900,000 adult returns from 1991 to present. In retrospect, gradual declines of coho production in PNCIMA were underway by the late 1960s, becoming pronounced by the mid-1990s, followed by modest rebuilding of the stock-aggregate after 1997 (Figure I.4f).

General factors controlling trends in salmon production in PNCIMA include the influence of exploitation by distant and domestic fisheries; climate-induced changes in freshwater and marine productivity; targeted stock and enhancement activities (Riddell 2004; Fisheries and Oceans Canada 2006); and the influence of forest harvest, agricultural development, mining and water regulation activities on salmon habitat (McAllister *et al.* 1997; Harvey and MacDuffee 2002). Only limited generalizations are possible about the specific influence of any one or combinations of these factors on trends in salmon abundance throughout PNCIMA. Long term trends for coho salmon declines appear to have been related to combinations of downturns in stock productivity combined with exploitation rates that were non-sustainable during the 1970s and 1980s (Holtby *et al.* 2002). Similarly, significant reductions in chinook catches, mandated by the Pacific Salmon Treaty beginning in 1985, were accompanied by increases in escapement and subsequent total production of chinook salmon in PNCIMA during the late 1980s to mid-1990s (Riddell 2004) but have declined, somewhat inexplicably, since the late 1990s. Industrial logging and agricultural development clearly have considerable potential to influence many local area salmon populations but no studies completed to date have offered definitive evidence that the extent of these activities in watersheds or coastal areas of PNCIMA are controlling salmon production (McAllister *et al.* 1997).

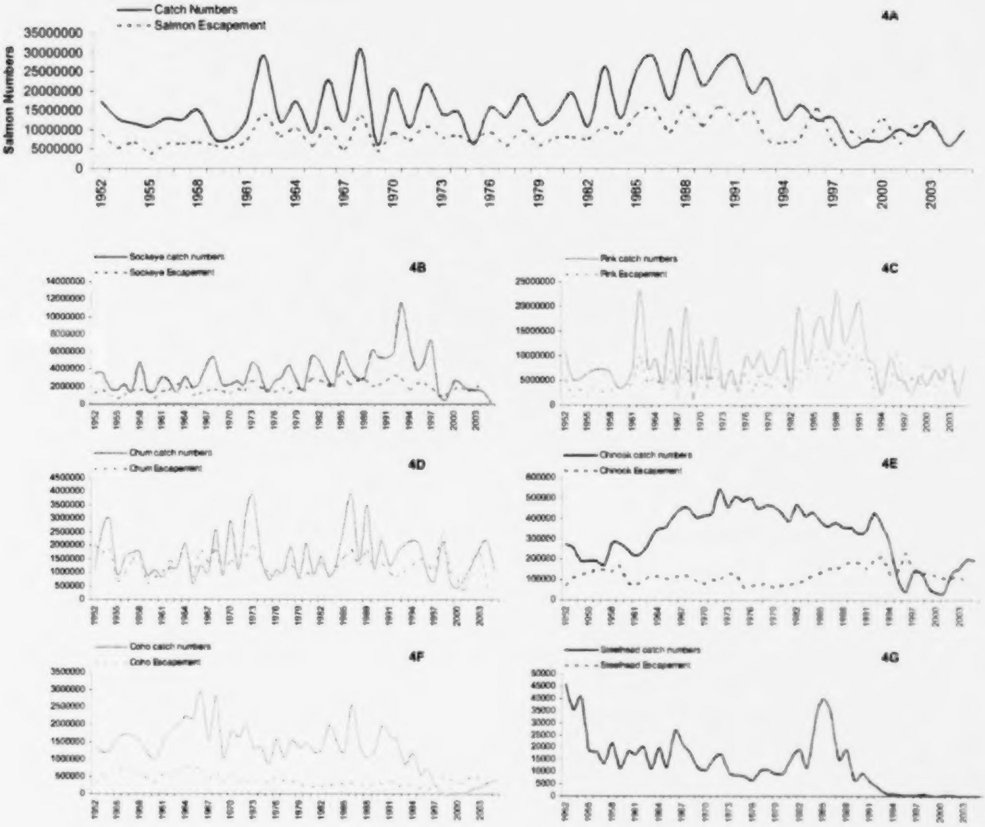


Figure I.4 Total annual returns (catch plus escapement) of (a) all salmon to PNCIMA between 1950-2004 including: (b) sockeye salmon, (c) pink salmon, (d) chum salmon, (e) chinook salmon, (f) coho salmon, and (g) steelhead (catch only). Data provided by DFO Salmon Assessment Section staff, Pacific Biological Station, Nanaimo, BC.

Mueter *et al.* (2002b) investigated spatial correlations between marine environmental variables and survival rate indices of salmon along the west coast of North America, including PNCIMA. Their analyses suggested that associations between salmon survival and near coastal environmental variables (upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]) were strongest at local spatial scales (distances of <500-800 km) for adjacent stocks and exhibited little or no co-variation at spatial scales larger than 1000 km. Among the three variables examined (upwelling, SST, and SSS), correlation scales for SST in summer most closely matched the observed correlation scales for survival rates of salmon. Moreover, regional averages of SST appeared to be better predictors of survival rates than large-scale measures of SST variability such as the Pacific Decadal Oscillation (PDO; Mueter *et al.* 2002a). This suggests that regional-scale variations in SST along the coast are related to the processes causing the observed co-variation in survival rates among neighboring salmon stocks such as Smith and Rivers inlets sockeye. Consequently, neighboring PNCIMA stocks may be expected to exhibit stronger similarities in survival and production variations than stocks separated by larger distances. Similar analyses, involving comparisons among stocks of sockeye, pink, and chum salmon suggested that geographical overlap of different salmon species during freshwater and early marine life stages are more important in determining shared environmental effects on survival rates (*and ultimately on stock productivity*) than are inherent differences in life history strategies between species (see Pyper *et al.* 2005 for details).

2.0 HISTORY OF EXPLOITATION AND MANAGEMENT

2.1 Salmon Exploitation – Aboriginal Fisheries

The abundant resources of the temperate Northwest Coast supported one of the world's densest non-agricultural, human populations for thousands of years prior to European contact. West coast peoples engaged in specialized hunting and fishing, crafts and curing; created social units larger than villages, elaborate ceremonies, and one of the world's great art styles (Harris 2001). Following Suttles (1990), indigenous cultural groups in PNCIMA include the Haida (Queen Charlotte Islands), Niska (Nass Valley), Gitskan and Coastal Tsimshian (Skeena River and coastal areas), Haisla (Kitimat, Gardner Canal and Kitlope area), Bella Coola, Heiltsuk and Southern Kwakiutl (northern Vancouver Island and mainland inlets).

The exploitation of fisheries, including salmon, has been described as the foundation of the Native economy (Drucker 1963), where orientation towards the sea and rivers regulated settlement patterns and was reflected in social organization, culture and religion (see pp. 18-19 of Augerot *et al.* 2005). The principal unit of social organization on the Northwest Coast was the local kinship group who lived together, worked together, and who jointly considered themselves exclusive owners of the tracts and sites from which food, including salmon, was obtained. Argue and Shepard (2005) note that the precise extent of Aboriginal utilization of salmon prior to first contact with Europeans (circa 1770s) is a matter for speculation. Pre-contact estimates of indigenous populations of people on the order of a hundred thousand or more (Duff 1965), combined with annual per capita consumption rate estimates of several hundreds of salmon, led Argue *et al.* (1990) to suggest annual utilization levels by Aboriginal populations of 18,000 tonnes (about 5.2 million fish), a level rivaling harvest by the early commercial fishery in the late 1800s. Thus Aboriginal harvest of Pacific salmon was substantial during the period prior to European settlement and salmon may be regarded as a "cultural keystone species" (Garibaldi and Turner 2004) that played a fundamental role in the diet, in addition to serving as cultural icons in the language, ceremonies, and narratives of Native peoples.

Population estimates for all Native groups in PNCIMA combined, and prior to first contact with Europeans, have been estimated at roughly 60,000 people (p. 136, Table 1 of Boyd in Suttles 1990). Native peoples throughout PNCIMA employed stone tidal-ponds in salt water and traps and weirs in rivers, as well as harpoons, leisters, dip-nets and trawl-nets to fish for salmon (see chapters on specific cultural groups in Suttles 1990). Although all species were eaten fresh, chum salmon were smoke-dried in great quantities for winter food supplies, because the fat content was lower and the product less likely to go rancid. The failure of a salmon run could presage a winter of privation and many myths refer to actual starvation (Cove 1978). Accordingly, the sites for harvest of salmon were prized and closely surrounded with a variety of "regulations" concerning access, entitlement, and moderation of salmon harvest both within and external to the kinship group (see references and descriptions in Harris 2001). Evidence presented by some authors (*e.g.*, see Cannon 1992) suggests that then, as now, relative variations in scarcity and abundance of salmon, along with control over access, promoted both trade and conflict between and among local fishing groups. However, both the details and the impact of Aboriginal management practices on salmon and their use are subjects for considerable speculation where current knowledge remains fragmentary. What may be said with certainty is that prior to 1880 the Pacific coast salmon fishery was largely a Native fishery controlled by a complex set of customs and regulations originating from centuries of Aboriginal culture.

2.2 Salmon Exploitation – Contemporary Fisheries

The development of the modern salmon fishery and associated management systems followed a similar pattern in all areas of the coast (Lyons 1969; Hyatt and Steer 1987; Argue and Shepard 2005). Use of fresh, salted, or dried salmon for subsistence purposes by fur traders and settlers from the early to mid 1800s was small (probably <200 tonnes) compared to use by Aboriginal peoples (Argue and Shepard 2005). However, by the late 1800s successful development of techniques for canning salmon, combined with developing export markets for the product, stimulated the creation of a capture and processing industry involving 20 canneries in 1880 increasing to more than 80 scattered throughout the BC coast by 1917 (Hyatt and Steer 1987). No fewer than half of these canneries were located in PNCIMA, including 6 on the Nass R., 14 on the Skeena R., 9 at

Rivers and Smith inlets, plus scores of others sited in inlets and at the mouths of rivers (Lyons 1969), wherever sufficient supplies of salmon could be captured by nearshore gill-nets or drag-seines (*e.g.*, see Appendix 2 of Campbell 2004 for specific locations of canneries in PNCIMA in 1932). Sockeye, coho, and chinook salmon comprised most of the rapidly increasing catch prior to 1900 when total harvest remained below 10,000 tonnes (Figure I.5). However, by 1910 all five species of salmon and steelhead were included in steeply increasing catches facilitated by the introduction of rapid technological change in all sections of the coastal industry (*e.g.*, see Hyatt and Steer 1987 for the typical progression in a salmon fishery). Salmon catch peaked above 40,000 tonnes in PNCIMA around 1928, only 4 years after a prohibition against use of motorized fishing vessels was rescinded (Figure I.5). Total catch of salmon fluctuated between 20,000 and 35,000 tonnes during 1930-1980 and then peaked above 40,000 tonnes again in the mid-1980s due to variations in the availability of both wild and enhanced salmon. However, while the catch circa 1928 was processed in no fewer than 46 facilities scattered throughout PNCIMA, technological change (*e.g.*, introduction of packers equipped with freezers or cold-brine circulating tanks) facilitated consolidation of transport and physical plants for salmon processing. By 1975, this had resulted in the closure of virtually all of the fish processing facilities located in mainland areas of PNCIMA from immediately south of the Skeena River in the north to Port Hardy on Vancouver Island (see Map 42 in Farley 1979).

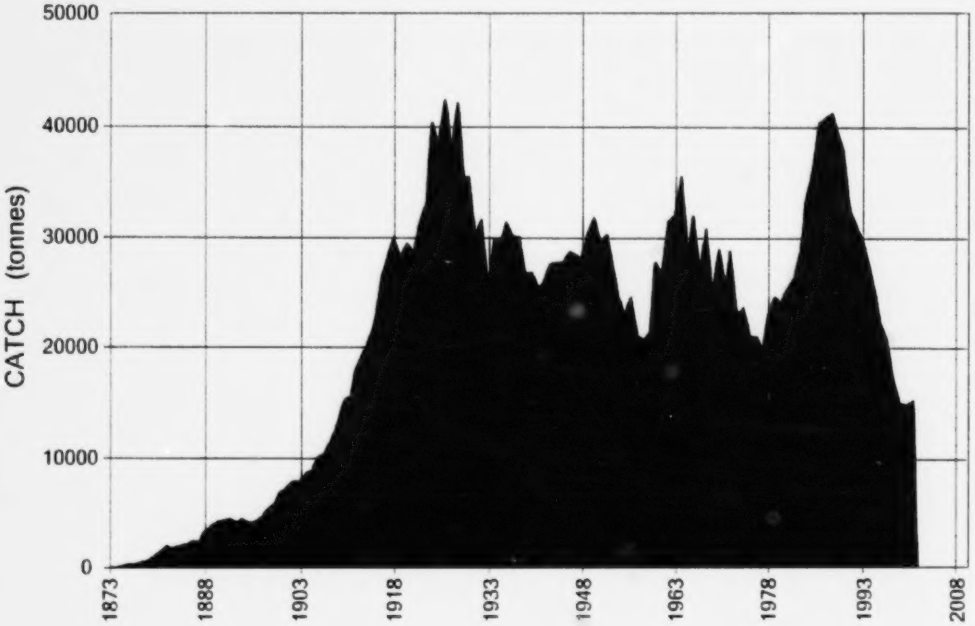


Figure I.5 Annual British Columbia catch (tonnes) of all salmon species, 1873-2001, within PNCIMA (DFO Statistical Areas north of Cape Caution). Catches summed across all species and presented as a 5-year moving average (from Argue and Shepard 2005).

Comparisons of the spatial distribution and species composition of salmon catches within PNCIMA in the 1950s (Figure I.6a), the 1970s (Farley 1979) and then again in the 1990s (Figure I.6b) suggest some obvious trends for coastal fisheries. First, catches of salmon generally reflect the relative abundance of species within or among areas such that pink and/or sockeye account for the largest proportions of catch, chum salmon are next, followed by coho, then chinook, and finally steelhead salmon. Next, salmon catches were more equitably distributed among areas of the coast in the 1950s than in more recent intervals. This reflects relatively recent decreases in demand for pink salmon that dominated catches in most areas in the 1950s and the greater consolidation of fishery effort focused on high-value sockeye salmon (compare Figure I.6a versus I.6b) at the mouths of the Nass R. (Area 3), Skeena R.(Area 4), and Johnstone Strait (Areas 11-12). Finally, coho salmon comprised a larger portion of the catch both from directed and incidental harvest during the 1950s than during the 1990s when coho declined and fisheries managers responded by restricting both directed and incidental catch in troll and net fisheries respectively (Holtby *et al.* 2002). Steep declines in total catch during the 1990s are attributable to a complex set of factors including: changes to harvest management to conserve and restore depressed populations affected by overfishing and environmental degradation in some areas (Harvey and MacDuffee 2002; Riddell 2004); climate-induced declines in the productivity of marine and/or freshwater ecosystems that support salmon populations associated with PNCIMA (*e.g.*, sockeye at Rivers and Smith inlets; McKinnell *et al.* 2001); and changes in the economics of the wild fishery driven by increasing costs (*e.g.*, for fuel and labour), increasing competition for market share (*e.g.*, from farmed salmon and highly productive Alaskan fisheries) and decreasing revenues.

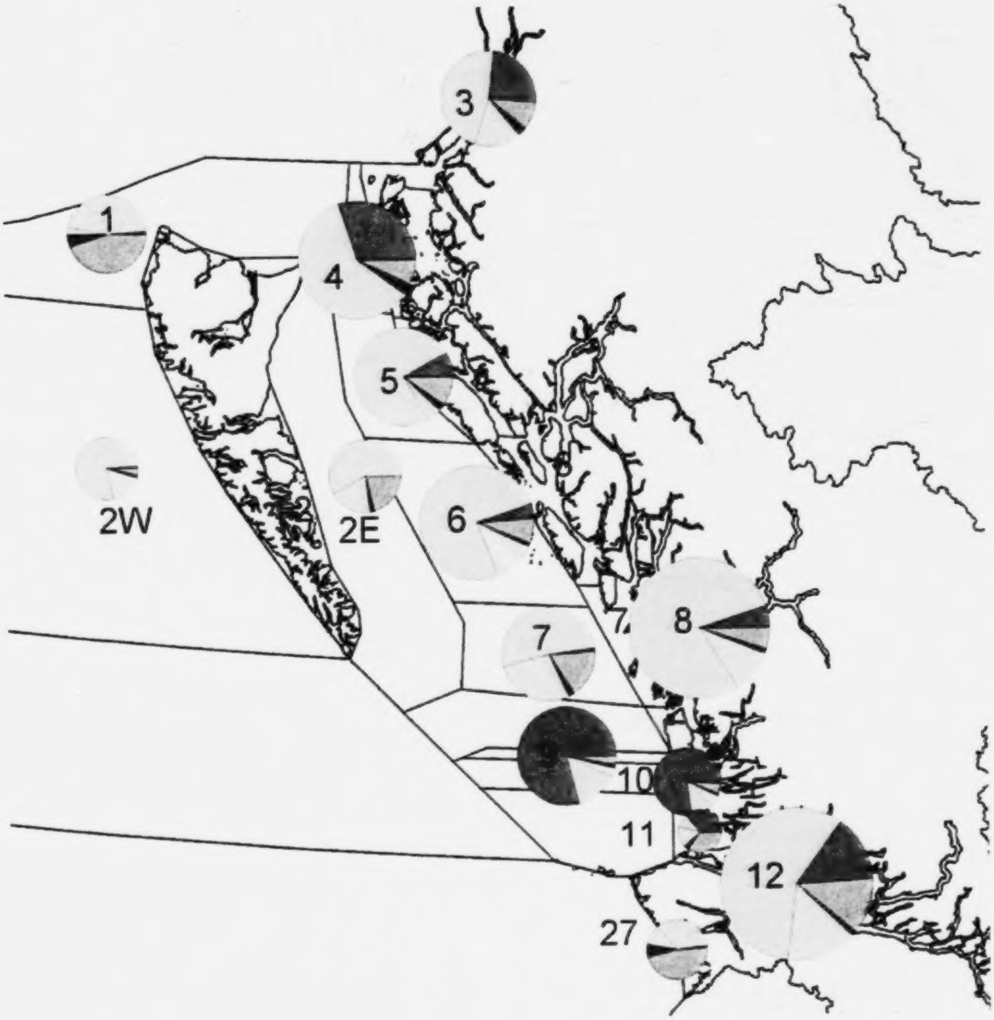


Figure I.6a Distribution of average catch of salmon within PNCIMA during 1951-1963 inclusive. Symbol sizes are scaled within time period to largest total catch by number in a statistical area. Species are identified by colours where: pink = pink salmon, red = sockeye salmon, gold = chum salmon, green = coho salmon, and blue = chinook salmon.

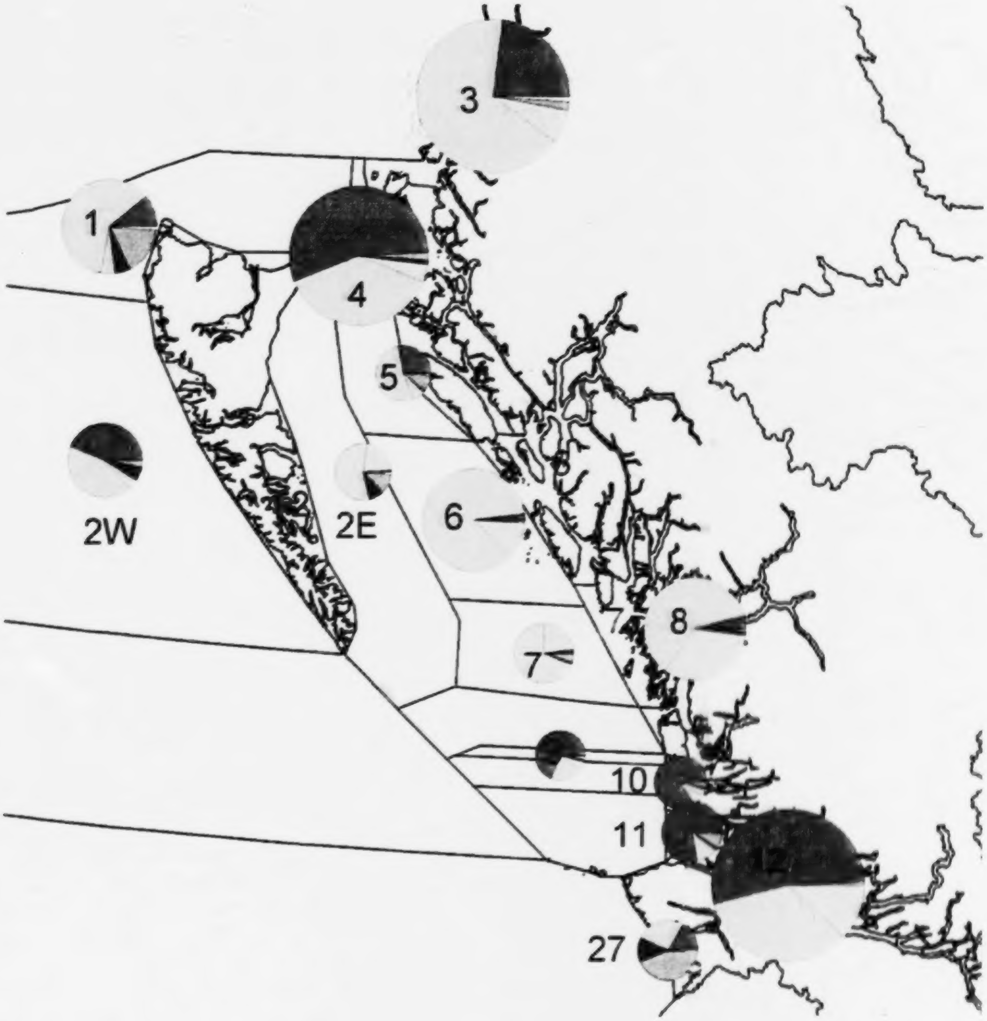


Figure I.6b Distribution of average catch of salmon within PNCIMA during 1992-2003 inclusive. Symbol sizes are scaled within time period to largest total catch by number in a statistical area. Species are identified by colours where: pink = pink salmon, red = sockeye salmon, gold = chum salmon, green = coho salmon, and blue = chinook salmon.

In addition to commercial fisheries, recreational fishing focused on chinook, coho, and steelhead salmon occurs in areas scattered throughout PNCIMA, but generally does not harvest a large proportion of the majority of salmon populations returning to watersheds there. However, very high-value recreational fisheries may focus significant effort on salmon stocks for which either exceptional biological traits (*e.g.*, large size) or exceptional surroundings (*e.g.*, pristine wilderness) generate high demand in some sub-areas of PNCIMA. Examples of these fisheries include coho and chinook fisheries operating out of lodges at Langara Island (QCI), at Hakai Pass and Dawson's Landing (Rivers Inlet and Central Coast), and Princess Royal Island. In addition, world renowned fisheries for steelhead salmon occur in many PNCIMA rivers including the Dean and Atnarko (central PNCIMA) along with many tributaries of the Skeena River system (northeast PNCIMA).

2.3 Salmon Management

Between the 1870s and 1880s, the industrial commercial fishery, based largely on the export of canned salmon, came to dominate the west coast fishery (Lyons 1969). Although the history of its development is beyond the scope of detailed treatment here, state control of both the Native and non-native fisheries was increasingly realized through implementation of provisions of the Fisheries Act of 1868 and subsequent provision of Fishery Regulations for the Province of British Columbia in 1894 (see Harris 2001 for an excellent account). Thus, by the early 1900s a previously scattered and small-scale salmon fishery had become a highly regulated industry. At the time of the 1920s peak catch of salmon, the licensed BC salmon fleet included about 4,600 gillnet, 2,600 troll, and 278 seine vessels from which the combined fishing power represented an increasing threat to the sustainability of the salmon resource. In 2003, following the Department of Fisheries and Oceans (DFO) interventions to achieve fleet and harvest effort reductions, there were 1,406 gillnet, 539 troll and 276 seine boat licenses on just over 2000 active salmon vessels. About 50% of these participate in various fisheries in PNCIMA. Throughout the last century, DFO and its predecessors have pursued the development of sustainable management of the salmon resource (Hyatt and Riddell 2000). Thus, harvest is regulated to ensure sufficient adults return to the spawning grounds to produce the next generation of fish. This is accomplished through a system of fishing licenses combined with enforcement of seasonal-time and statistical-area (see Figures I.6a and b) restrictions to control catch and effort by gear types (*e.g.*, recreational, troll, gillnet, seines) in specific areas (Figure I.7) or by sectors (*i.e.*, Native, recreational, and commercial) of the salmon fishery.

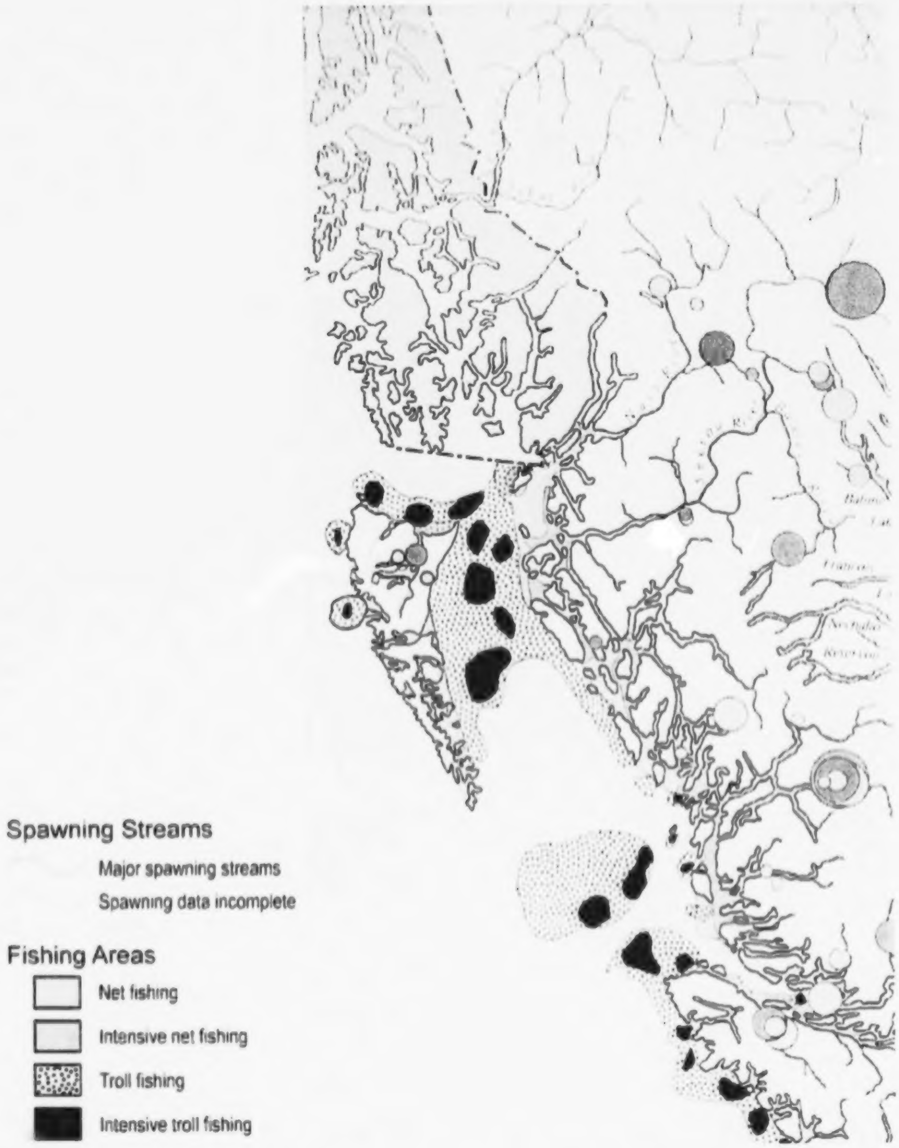

Spawning Streams
Major spawning streams
Spawning data incomplete
Fishing Areas
Net fishing
Intensive net fishing
Troll fishing
Intensive troll fishing

Figure I.7 Major and minor areas of operation for the British Columbia troll and net-fishing fleets. Alaskan net fisheries also exist near Noyes Island and Cape Fox (*i.e.*, just across the US-Canada border with Alaska) to intercept salmon bound for the Nass and Skeena rivers of PNCIMA (from Farley 1979).

The major components of contemporary management of major and minor salmon fisheries in PNCIMA (>50 separate fisheries in 2005 alone, Fisheries and Oceans Canada 2006) involve: (1) developing concurrent biological, economic, social, and legal objectives; (2) forecasting run size and formulating fishing plans; (3) consulting with user groups; (4) finalizing fishing plans; (5) executing fishing plans; and (6) evaluating management impact on the resource (*e.g.*, see Sprout and Kadowaki 1987). Details of the current policy context, management objectives, decision guidelines, and specific management measures by fishing area and subject species in PNCIMA are provided annually in an integrated fisheries management plan for northern BC salmon (Fisheries and Oceans Canada 2006). Briefly summarizing from that plan here, DFO policy for management of the fisheries is guided by a range of factors that include international and domestic initiatives that promote biodiversity, and a precautionary, ecosystem based approach to the management of marine resources. The latter entail implementation of international or domestic policy and operational initiatives outlined in: The Canada-US Pacific Salmon Treaty, Canada's Policy for the Conservation of Wild Salmon (WSP, see section 6.0 for more details), An Allocation Policy for Pacific Salmon, A Policy for Selective Fishing, A Framework for Improved Decision Making in the Pacific Salmon Fishery, and Catch Monitoring. These initiatives, among others, have been taken to ensure progress towards satisfying four key themes in the management of Pacific salmon fisheries (Fisheries and Oceans Canada 2006, p. 16, Section 2.4), which are: (1) sustaining strong salmon populations by setting clear conservation objectives for each fishery, based on the principles of the Wild Salmon Policy; (2) strengthening DFO programs that are critical to salmon conservation, such as habitat protection, enforcement, and the scientific assessment of stocks; (3) making progress over time in increasing First Nations access to economic fisheries; and (4) improving the economic performance of fisheries so that they reach their full potential, provide certainty to participants, and optimize harvest opportunities.

3.0 STOCK AND FISHERY ASSESSMENT PERFORMANCE INDICATORS

Given the great biodiversity of salmon populations found within PNCIMA, the complexities of their life histories and of the fisheries that harvest them, a wide range of stock and fishery performance indices are used to assess status and trends of Pacific salmon (McDonald 1981). Catch and escapement are principal among these, but a variety of additional information types (*e.g.*, biological traits such as size and age, migratory timing, preferred migration routes, etc.) are assembled to inform management decisions, dependent on the salmon species and the type of fishery (recreational, subsistence, commercial troll, or net). For example, sockeye, pink, and chum salmon are primarily intercepted by gillnet and seine fisheries at inshore locations (Figure I.7, net fishing) as the fish follow the coastlines of southeast Alaska and then sub-areas of PNCIMA during return migrations to their watersheds of origin. Information from pre-season forecasts of expected abundance, in-season assessments of catch and escapement to date in one or more fisheries, assessments of stock composition where returns consist of salmon stock mixtures (*e.g.*, large mixed stock fisheries for Skeena or Nass sockeye in Areas 3-5, Sprout and Kadowaki 1987, or passing stocks of Fraser River sockeye harvested in Area 12), plus knowledge of average return timing patterns, is used by fisheries personnel to adjust harvest activities to ensure enough spawners escape the fishery to sustain contributing stocks and the fishery in future years. Forecasts of adult returns are generally based on pre-fishery indices of abundance such as the abundance of seaward migrating juveniles or the number of adult spawners from which a given year's return is derived. Because fisheries for sockeye, pink, and chum salmon occur in a limited number of discrete locations, harvest monitoring and biological sampling efforts are focused in these locations to support annual abundance estimates of each stock. The reliability of these estimates depends greatly on whether the fishery involves a single stock (*i.e.*, highly reliable), simple mixtures of several major stocks (*i.e.*, medium to high reliability), or complex mixtures of a few major and many minor stocks (*i.e.*, reliable for major stocks but much less so for minor ones).

Chinook and coho salmon are caught not only near their watersheds of origin by restricted-area, gillnet and seine fisheries (often as bycatch) but also in hook-and-line fisheries (*e.g.*, commercial troll and recreational gear) dispersed throughout United States (US) and Canadian coastal waters. Consequently, hundreds of coho and chinook salmon populations may co-occur for varying intervals in a given harvest area such that the stock composition of catches is both complex and subject to rapid change. Moreover, reliable spawner enumeration of chinook and especially coho salmon is frequently problematic due to their use of either highly dispersed or inaccessible spawning sites (large, deep river channels by chinook, thousands of small headwater tributaries by coho) where assessment procedures are difficult to execute. Thus, sampling strategies and performance indicators to assess the status, track trends, and manage coho and chinook salmon are dependent on (1) development and maintenance of a limited number of "indicator" stocks for which high quality information is assumed to represent the status and performance of all stocks of a given species in each major area of the coast (Holtby *et al.* 2002 for coho; Riddell 2004 for chinook) and (2) maintenance and application of information from a coast-wide, coded-wire-tag (CWT), mark-and-recovery program operated jointly by Canada and the US.

The CWT program allows the systematic recovery of tags to assess the spatial distribution of catch and stocks, exploitation rates, and ultimately marine survival rates of marked juvenile chinook and coho salmon originating from index stocks that appear in various ocean commercial and recreational fisheries. Region-specific trends in marine survival, along with estimates of escapement for stock aggregates, are used for assessment and as a basis for forecasts of future abundance (*e.g.*, Holtby *et al.* 2002) to determine sustainable harvest levels for chinook and coho salmon. Coho index stocks in PNCIMA are located at Lachmach River, Toboggan Creek, and the Fort Babine Hatchery. Various chinook populations scattered throughout PNCIMA are used to follow trends in escapement (CTC 2004b). Kitsumkalum chinook, originating in a tributary to the Skeena River, serves as the only exploitation rate indicator (McNicol 1999) for North and Central Coast mixtures of Canadian stocks harvested by Alaskan and Canadian fisheries (CTC 2004a).

4.0 THE SALMON-HABITAT COMPLEX OF PNCIMA

Adaptive radiation of the Pacific salmon species complex following the most recent glacial retreat around 12,000 B.P. has resulted in thousands of locally distinctive populations that occupy freshwater and marine habitats throughout PNCIMA. To understand the full range of habitats occupied and the importance of its condition for maintenance of both salmon biodiversity and sustainable fisheries requires a brief consideration of key life history details that influence the distribution and abundance of the various salmon species and then a description of the current state of the salmon-habitat complex in PNCIMA.

4.1 Salmon Life Histories

Authoritative reviews of Pacific salmon life histories (Groot and Margolis 1991) provide key life history details related to species habitat requirements as follows.

4.1.1 Pink Salmon

Pink salmon (*O. gorbuscha*) are the smallest (1.5-2.5 kg) species of Pacific salmon and the least dependent on the freshwater environment. The center of pink salmon distribution in the eastern Pacific lies between south-central and southeastern Alaska. Thus, pink salmon in PNCIMA are located within the southern third of the species range in North America. Given their small body size, pink salmon are not especially adept at negotiating high velocity barriers or waterfalls that other Pacific salmon can surmount. Thus, most pink salmon populations migrate relatively short distances into rivers (typically less than 100 km) and in many short, coastal streams make significant use of inter-tidal areas where they spawn in large aggregations. Pink salmon spawning beds consist primarily of coarse gravel with a few large cobbles, a large mixture of sand, and a small amount of silt. Given their small size, pink salmon select spawning sites in relatively fast currents (as opposed to areas of sub-gravel upwelling) that facilitate gravel displacement during redd construction by females. Pink salmon have a fixed two-year life cycle such that they occur as even- or odd-year cohorts, which are reproductively isolated, even among those that use the same spawning streams year after year.

The peak of pink salmon returns to coastal rivers of PNCIMA occurs in July and August with spawning concentrated in late August and September. Pink salmon fry emerge from redds in March and April when they migrate immediately to sea. Pink salmon fry occupy near-shore waters of estuaries and coastal inlets for several weeks to months of time when feeding and growth depend on zooplankton and epibenthic organisms derived from estuarine and detritus-based food-webs. Following their estuarine and/or coastal inlet transition, pink salmon rapidly migrate northwest through PNCIMA waters to the Gulf of Alaska (GOA) before returning as adults to fresh water having spent more than a year at sea. Pink salmon exhibit less fidelity to their stream of birth than other species and so there are high rates of gene flow among local populations which, in aggregate, make up a few large regional meta-populations that are genetically similar.

4.1.2 Chum Salmon

Chum salmon (*O. keta*) are the second largest (3-6 kg) species of Pacific salmon. The distribution of chum salmon in North America is similar to that of pink salmon except that chums are found in appreciable numbers both further north and south than pink salmon. They are closely related to pink salmon (Allendorf and Utter 1994) and like the latter spend minimal time as juveniles in fresh water. They spawn in the lower reaches, side channels and tributaries of gravel-bed rivers, and spawning sites are often associated with upwelling groundwater along the margins of streams and in side-channels. In short coastal streams, chum may spawn in areas of tidal influence but rarely occupy the lower, inter-tidal areas commonly used by pink salmon. Given large body size, chum salmon are powerful swimmers and adept at long distance migrations. However, they are not great leapers and are generally found below the first barrier of any significance in a river.

Chum salmon return to coastal waters and rivers of PNCIMA in July through September with spawning concentrated in late September to early November. Early and late spawning runs of chum salmon are very common throughout their range, where early or summer-run adults utilize mainstem, spawning locations while fall-run fish use upwelling groundwater areas that maintain higher incubation temperatures through the winter. Chum salmon fry emerge from the gravel in March and April and migrate immediately to coastal estuaries where diets are frequently dominated by amphipods and benthic copepods. Chum salmon spend 2-4 summers at sea returning as 3-5 year-old adults to spawn in fresh water. Chum salmon exhibit considerable fidelity to their natal spawning areas and consequently exhibit higher levels of genetic differentiation and a larger number of distinctive population units within PNCIMA than pink salmon do.

4.1.3 Sockeye Salmon

Sockeye (*O. nerka*) are the fourth largest species of Pacific salmon in terms of average weight, which ranges between 1.5-3.5 kg. The latitudinal distribution of sockeye salmon is similar to that of pink salmon, so sockeye salmon in PNCIMA represent populations in the southern half of the species range in North America. Spawning and rearing habits of sockeye are both variable and complex. They routinely spawn in the mainstems or side-channels of gravel-bed rivers, in groundwater-fed springs, or on gravel beaches and outwash fans of lakes. Although sockeye populations are commonly associated with lakes used by juveniles for 1-3 years after fry emergence, there are also many small, relatively unproductive populations that spawn in rivers and streams that lack obvious lake rearing areas. Fry of these sockeye populations rear in side channels of rivers, in coastal estuaries or may migrate to sea soon after emergence. Sockeye production in PNCIMA is dominated by a few highly productive populations associated with large lakes located on the coast and far inland (*e.g.*, Babine Lake on the Skeena R.) but there are scores of small populations in the short river and lake complexes distributed throughout PNCIMA (Figure I.2c). Sockeye are strong swimmers and good jumpers, so they gain access to habitat above cascades and barriers that neither chum nor pink salmon negotiate.

Sockeye salmon returns to coastal waters and rivers of PNCIMA occur from June through August followed by spawning from mid-September to mid-October. Sockeye fry emerge from redds in March-May, depending on whether they are interior or outer coast populations, at which time they generally migrate either downstream (for lake inlet populations) or upstream (for lake outlet populations) to a nursery lake where they spend 1-3 years rearing before initiating seaward migration. During lake residence, sockeye principally occupy offshore waters and commonly exhibit daily vertical migrations from deep-water refuges during the day to near surface waters at night where they feed primarily on pelagic zooplankton but also on chironomids and aquatic insects. Thus, sockeye are the only species of Pacific salmon in PNCIMA that make extensive use of the offshore habitats and zooplankton prey found in the many lakes of the region. After 1-3 summers rearing in fresh water, sockeye migrate seaward during the interval from early April (southern PNCIMA) to late May (northern PNCIMA).

During the early portion of marine life, juvenile sockeye generally move northwestward at rates of 6-7 km per day. Consistent with their freshwater diets, sockeye consume zooplankton (copepods, euphausiids), small larval fish, and occasionally amphipods during early marine life. Comparative studies of the diets of sockeye, chum, and pink salmon during early marine residence suggest that, although many food categories are shared, each species tends to concentrate on different prey, resulting in a broader utilization of the full spectrum of foods in estuarine and continental shelf waters than would occur otherwise. By the fall of their first sea entry year, juvenile sockeye from PNCIMA have largely cleared the area for the coastal waters of southeast Alaska and later the GOA (Hartt and Dell 1986). Sockeye salmon spend 2-4 summers at sea before returning as adults (ages 3-6) to spawn in fresh water. Both adult and juvenile sockeye salmon exhibit very high levels of homing to their natal spawning and lake-rearing areas and consequently exhibit enough reproductive isolation that populations in each lake and river complex exhibit distinctive, behavioural, morphological, and genetic differentiation (Nelson *et al.* 2003).

4.1.4 Coho Salmon

After chinook and chum, coho salmon (*O. kisutch*) are the third largest species of Pacific salmon (2.5-5 kg) and coho weighing up to 6 kg are not uncommon. Although the latitudinal expanse of coho salmon in North America is similar in magnitude to species such as sockeye, chum, or pink salmon, coho salmon are more tolerant of conditions found in watersheds further to the south (*e.g.*, as far south as the Sacramento R. in California) than the former species. In PNCIMA, as elsewhere, a multitude of small populations spawn and rear from 1-3 years in small headwater tributaries to side-channel habitats of river mainstems. Coho salmon are powerful swimmers and excellent jumpers that readily surmount small waterfalls, beaver dams and velocity barriers to penetrate high into the headwaters of small, often ephemeral tributary streams. Coho salmon are less likely than other species to spawn as large aggregates but more often as solitary pairs in pockets of gravel dispersed among large boulders in headwater areas of hundreds of small streams.

The peak of coho salmon returns to coastal waters and rivers of PNCIMA occurs in August to September but both return timing and spawning are often protracted enough that coho salmon comprise the last of several waves of salmon species moving upriver in association with early winter rains. Coho fry emerge from redds in March and April at which time they disperse downstream and into side-channel and off channel habitats to rear. Juvenile coho salmon may spend 1-3 years rearing in stream and side-channel habitats with an abundance of pools and woody debris for cover. Juveniles of some populations also rear in the littoral zones of lakes, but only rarely use offshore waters in such locations, and never in the presence of planktivorous species such as sockeye salmon. Juvenile coho diets in fresh water are commonly dominated by terrestrial insects and a wide range of stream invertebrates. After 1-3 years in fresh water, coho salmon migrate to sea where they feed principally on fish and a wide range of marine invertebrates. Coho salmon commonly exhibit less extensive marine migrations than pink, chum, or sockeye salmon and spend more time in inshore coastal waters closer to their watersheds of origin. Coho salmon spend 1-2 summers at sea usually returning as 2-3 year-old adults to spawn in fresh water. Adult and juvenile coho salmon exhibit higher straying rates from their natal streams for both spawning and freshwater rearing than sockeye, chinook, or chum salmon. Consequently, dozens to hundreds of small populations of coho salmon in a given region may be closely related and form a single large meta-population exhibiting little genetic differentiation among many watersheds.

4.1.5 Chinook Salmon

Chinook salmon (*O. tshawytscha*) are by far the largest of the Pacific salmon (routinely 5-11 kg). The latitudinal extent of chinook salmon is such that the populations in PNCIMA fall roughly in the middle of the range for this species. Chinook salmon spawning aggregations occur principally in mainstem rivers and they may exhibit multiple timing groups such that in the largest river basins (*e.g.*, Skeena, Nass) there are some adult chinook returning in most months of the year. However, peak returns usually occur between May and September.

Although the life history patterns of chinook salmon are highly varied, two basic life history types are differentiated by the temporal duration of freshwater rearing. Stream-type chinook salmon rear as juveniles for up to 2 years in fresh water before migrating to sea. In PNCIMA most stream-type chinook originate from large, interior river basins (*e.g.*, Skeena R., Nass R.) where spawning and rearing habitats are influenced by continental climates characterized by warm, dry summers and cold winters. By contrast, within a few weeks to months of fry emergence, ocean-type chinook salmon migrate to sea from their home rivers and then spend 4-5 years rearing in marine waters where they may either undertake extensive migrations or alternately remain close to their watersheds of origin. Chinook populations originating from the smaller river systems scattered along the coast of PNCIMA are generally ocean-type.

Chinook salmon fry feed on a wide range of terrestrial insects and aquatic insects when rearing in fresh water, but become highly piscivorous at larger sizes during their period of marine rearing. Chinook have one of the lowest straying rates of any of the species of Pacific salmon and accordingly exhibit high levels of behavioural, morphological, and genetic differentiation among widely scattered populations (Figure I.2f).

4.1.6 Steelhead Salmon

Steelhead salmon (*O. mykiss)* vary greatly in size (routinely 2.5-9 kg). They exhibit the most southerly coastal distribution among Pacific salmon in the eastern Pacific such that their populations in PNCIMA fall principally in the northern half of the range for this species. Thus, although there are significant populations of steelhead returning to the Skeena River mainstem and its tributaries, there is little evidence of large populations of this species further north in any of the major rivers of southeast Alaska. Steelhead salmon live for 4-7 years and, by contrast with other Pacific salmon, may spawn in each of several years of their adult life. Steelhead salmon adapt to a variety of conditions and utilize all parts of a river basin, from small tributary streams to mainstem river channels (Augerot *et al.* 2005). Their life histories vary widely and include diverse combinations of fresh water, estuarine, and marine residence. However, in general, their populations are quite small. Adult steelhead salmon are common to many rivers of PNCIMA and return over a protracted period during both summer (*i.e.*, summer-run) and winter (*i.e.*, winter-run) with spawning taking place for both run-timing groups from late winter to late spring. Steelhead complete extensive ocean migrations but because of their relative scarcity, details of their life histories are more fragmentary than for the other species of Pacific salmon.

4.2 The Habitat Context for Salmon in PNCIMA

British Columbia's PNCIMA covers the coastal waters, islands, and watersheds of the Canadian Pacific from the Alaskan border south to Johnstone Strait and from the summits of the Coast Mountain range west to the continental slope. It includes Haida Gwaii/Queen Charlotte Islands (QCI) and northern Vancouver Island. Considered from the perspective of Pacific salmon, the region consists of a Large Aquatic Management Area (LAMA) containing a complex of freshwater habitats scattered across a 118,000 km^2 landscape (more than twice the size of Belgium) and a large ocean management area (LOMA) defined by scores of estuaries, fjords, and open continental shelf seascapes covering 107,000 km^2. The region is in the heart of the Northeast Pacific archipelagic coast, and globally is one of only two large glaciated coastal realms (the other being southern Chile).

4.3 Salmon Habitat and Eco-zones in the LAMA

The LAMA portion of PNCIMA is varied, consisting of lowlands, intricate coastlines, extensive floodplains, and coastal mountain ranges with deeply incised valleys and steep-sided fjords. The climate is cool (mean annual temperatures range from 5°C to 10°C) and wet (mean annual precipitation ranges from 1,000-4,500 mm). The LAMA divides into four broad regions - Lowlands, Haida Gwaii Insular Mountains, Outer Coast Mountains, and Inner Coast Mountains - differing in topography, climate, hydrology, natural disturbance regimes, and ecosystems (BC Coast Information Team 2004). Trainor (2001) provides a map and describes the existing biogeoclimatic and physiographic boundaries that delineate the four regions.

The Lowlands form narrow, low lying, boggy strips along the coast and islands. Precipitation is high, but annual snowfall is relatively low. The Insular, Outer Coast, and Inner Coast Mountain regions all feature steep, rugged mountains, ocean fjords, and watersheds of variable size. These mountainous regions are distinguished primarily by climate: the Insular Mountains are very wet and cool with little snowfall, the Outer Coast Mountains are very wet and mostly cool with heavy snowfall, and the Inner Coast Mountains are drier with warmer summers and heavy snowfall. The four major regions can be further subdivided into at least 11 sub-regions according to glacial runoff and hydrology (BC Coast Information Team 2004). Thus, rivers and watersheds with hydrology dominated by snowmelt (*e.g.,* Nass, Skeena, Kitlope) exhibit minimum flows from December to January and peak flows from June to July. By contrast, Lowland and Outer Coast watersheds with rainfall dominated hydrographs (*e.g.,* Yakoun, Copper, Keogh, Nimpkish) exhibit peak flows from November to January and minimum flows from August to October (Farley 1979).

The LAMA portion of PNCIMA includes 45% of North America's three temperate, rainforest ecoregions and contains the largest remaining expanses of intact temperate rainforest in the world (BC Coast Information Team 2004). Natural disturbances, along with the activities of First Nation's peoples, have historically shaped the composition and structure of these forests that play a major role in controlling the structure and ecological processes that influence both the quantity and quality of habitat used by Pacific salmon throughout the area. Natural disturbances that replace forest stands in the LAMA are rare, so old growth forest (and relatively stable biological communities) dominates valley bottoms, riparian corridors, and the lower slopes of mountain areas.

Geomorphic disturbances, such as landslides and snow avalanches, are the primary natural agents of stand-replacing disturbance in wet, steep coastal forests. Wind (generally restricted to the exposed portions of the Insular Mountains and northern Vancouver Island) and fire (generally restricted to the Inner Coast Mountains) may also occasionally create large openings in the forest canopy of the LAMA. Return intervals for these stand-replacing events are on the scale of millennia throughout the majority of the area. Flooding is a key process shaping floodplains, river-fans and estuaries, which are highly productive biodiversity hot spots (BC Coast Information Team 2004). The different types of disturbance do not occur homogeneously across the forest landscape, with the result that a forest mosaic has emerged consisting of large, continuous tracts of all-aged, structurally diverse old-growth forest composed principally of western hemlock and, in wetter lowland areas, red cedar. Pearson (2003, cited in BC Coast Information Team 2004) found the area of forest land disturbed in a Central Coast study plot over the past 140 years amounted to only 0.3%, 1.4% and 1.3% of the total area from wind, geomorphic (*i.e.,* landslides, avalanches, and flooding), and fire disturbance-events respectively. Fire was limited to the Inner Coast Mountains, wind was limited to the Lowlands, and geomorphic disturbances occurred throughout the area.

Within the LAMA portion of PNCIMA, the Coastal Western Hemlock and Mountain Hemlock biogeoclimatic zones cover about 80% of the landscape. Moreover, in this wet, cool coastal environment, hydroriparian ecosystems commonly utilized by Pacific salmon are particularly prevalent. In the Lowlands, wetlands (bogs, ponds, and small lakes) cover 51-75% of the landscape (Banner *et al.* 1986; 1988 cited in BC Coast Information Team 2004). Small, low-gradient streams are very common, draining extensive slope/blanket bogs. There are many small but few large estuaries and floodplains, because Lowland watersheds are small and primarily rain fed. Exposed marine shores are common. The Insular and Coast Mountains contain a variety of hydroriparian ecosystems, including small, steep headwater streams and gullies, running down into fans and floodplains. Moderately sized lakes head some valleys and a variety of small wetlands dot floodplains. In these mountainous regions, large estuaries fed by rivers (*e.g.,* Skeena, Nass, Bella Coola, Kitimat, Kitlope), rain, glaciers, and permanent snow are common. Because of their diverse forms, relatively frequent disturbance and high productivity, hydroriparian ecosystems throughout PNCIMA are home to distinctive assemblages of plants and animals and are hotspots of regional biodiversity. However, in general, biological communities of the LAMA exhibit considerable stability over centuries of time with respect to dominant forest cover (*e.g.,* old growth hemlock, cedar, and fir) that plays a major role in shaping both the quality and quantity of habitat available for various species of Pacific salmon.

4.4 Salmon Habitats of the Marine Portion of PNCIMA

The oceanic portion of PNCIMA is a submarine continuation of the LAMA known as the Queen Charlotte Basin (QCB) which can be considered a semi-enclosed sea (see Chapter 1: Ecosystem Description, Appendix A: Geology, and Appendix B: Meteorology and Climate). At its northern end, the QCB connects to the offshore via Dixon Entrance. The central portion of the basin, known as Hecate Strait, is relatively protected from the open NE Pacific by the Queen Charlotte Islands. Further south, the basin is more exposed, and is contiguous with the offshore NE Pacific via Queen Charlotte Sound. Thomson (1981) notes that from an oceanographic point of view, the QCB is a hybrid region, similar in many respects to the nearby offshore waters of the Pacific but considerably modified by estuarine processes characteristic of protected inland coastal waters. Ware and McFarlane (1989) considered the QCB to be part of the Coastal Downwelling Domain (CDD) extending from Queen Charlotte Sound to the Aleutian Islands. The prominent circulation features in this region are the poleward flowing Alaska Current, and Alaska Coastal Current, where the latter is driven by freshwater runoff in northern BC and southeast Alaska. The Alaska Coastal Current extends seaward about 40 km from the coast, flows at an average speed of some 20 km d^{-1} and links conditions in the QCB to conditions and events in the Gulf of Alaska where most sockeye, pink, and chum salmon populations spend 1-3 years rearing following their northwesterly migration through the QCB during their first year of sea entry. See Appendix C: Physical and Chemical Oceanography for more about ocean currents influencing PNCIMA.

The diverse marine habitats that salmon utilize in the QCB are created by complex, seasonal interactions among bathymetry, wind, freshwater runoff, and tidal currents that control both the circulation of water and its properties within the QCB (Thomson 1981). Although the detailed patterns of salmon utilization of these varied marine habitats are less well studied than their use of freshwater habitats, several generalizations are possible. From a salmon habitat perspective, the waters of the QCB may be viewed as consisting of: (1) transitional, estuarine staging, and rearing areas for the juvenile and adult stages of all species (*e.g.,* coastal inlets and major estuaries of the Nass and Skeena rivers); (2) upwelling areas of productive underwater shoals and banks that are especially important as rearing areas for aggregations of sub-adult coho and chinook salmon (Dogfish, North Island, Goose, and Cook banks); (3) continental-shelf, surface-water eddies that may entrain juvenile salmon and plankton for periods of days to weeks (*e.g.*, clockwise rotating Rose Spit Eddy and the counter-clockwise flowing Queen Charlotte Sound Eddy, Crawford *et al.* 1995); and (4) advection zones along the continental shelf where surface waters may move rapidly seaward as filaments or plumes with replacement from depth by upwelling nutrient rich waters. Historic surveys of the distribution and abundance of juvenile salmon suggest differential use of these areas across seasons (Hartt and Dell 1986). Thus, in early spring and summer, juveniles of all species are found aggregated in nearshore inlets and estuaries serving as their points of sea entry (*e.g.,* Skeena, Nass, Bella Coola, etc.). However, by October, juvenile salmon of all species are found somewhat further offshore concentrated in pelagic, surface waters (<50 m) located between the 100 m and 1000 m isobaths over the continental shelf (Figure I.8, after Welch *et al.* 2007). All Pacific salmon species, whether rearing in or migrating through the QCB, tend to aggregate in near-shore waters of the continental shelf. The virtual absence of juvenile salmon in offshore waters of PNCIMA (Figure I.8) underscores the importance of near-shore areas to salmon populations originating from watersheds within and external to the QCB.

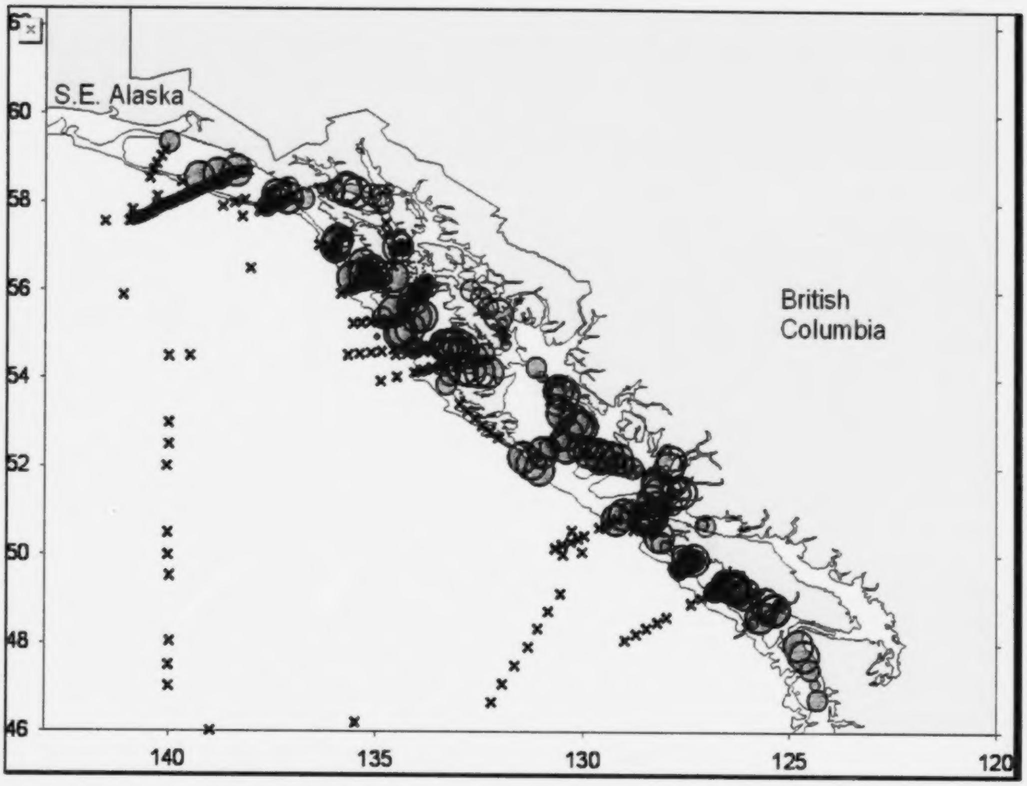


Figure I.8	Distribution of juvenile salmon catches of all species off the west coast of North America in October (all species combined). The size of circles is proportional to the number of fish caught (smaller means fewer). The Xs represent locations fished without catching salmon. The 200 m and 1000 m isobaths are indicated (from Welch *et al.* 2007).

Conditions (current fields, thermal regimes, salinity gradients, prey density, etc.) encountered by salmon in the marine habitats of the QCB are dominated either directly or indirectly by powerful but remote climate systems (see Appendix B: Meteorology and Climate). The latter are controlled in fall and winter by the Aleutian Low and in spring and summer by the North Pacific High that influence seasonal and annual to multidecadal variations. In contrast with the relative stability of habitats and biological communities observed over centuries of time in the LAMA, habitats and biological communities in marine portions of the QCB exhibit much more variation where sudden shifts in atmospheric forcing over either the subtropical or North Pacific are linked to rapid changes in upper ocean conditions and the organization of biological communities. Thus, El Niño Southern Oscillation (ENSO) episodes off of Peru are associated with intensification of the Aleutian Low and westerly winds at mid-latitudes in the North Pacific, leading to a stronger than normal poleward advection of warm water along the coast of North America every 7-12 years on average (Ware and McFarlane 1989). Similarly, a reversal of these conditions to a relatively cold La Niña state frequently appears immediately after major ENSO events. Zooplankton standing stocks in the QCB dropped steeply during the 1997 El Niño event. Similarly, El Niño-La Niña episodes appear to influence the distribution and abundance of large migratory hake in the QCB such that they are abundant in warm El Niño years but virtually absent in cool La Niña years (Cooke in Department of Fisheries and Oceans 2006). In addition, although the causal mechanisms are poorly understood (Schwing *et al.* 2005), statistical analyses of Pacific Ocean and atmosphere fields for the twentieth century have revealed spatial patterns that remain relatively steady for 10-30 years (regimes), followed by a rapid change or "regime shift" within a few years to another relatively stable pattern (various authors in King *eds*. 2005). Evidence suggests the occurrence of climate regime shifts in 1977, 1989, and 1998 in the North Pacific. Thus, after 1977, the Aleutian Low intensified, resulting in a stronger Alaska Current, warmer water temperatures, increased coastal rain, and increased water column stability.

A doubling of zooplankton biomass between the 1950s-60s and in the 1980s indicates that production was positively affected after the 1977 regime shift (Brodeur and Ware 1992) and accompanied by improvements in recruitment and survival of salmon in the Gulf of Alaska and northern portions of the QCB. By contrast, the 1989 regime shift was accompanied by cooler waters and more variable conditions in the Gulf of Alaska, and survival of at least some of the salmon stocks in the QCB (*e.g.*, several sockeye and pink salmon populations in the Central Coast) plunged steeply along with declines of QCI herring stocks (Boldt *et al.* 2005). The mechanisms controlling these periodic physical and biological changes in the eastern Pacific and QCB do not fit neatly into the concept of inverse production regimes suggested by Hare *et al.* (1999) for northern versus southern salmon stocks. However, it is highly likely that similar large-scale, but poorly understood oceanic production processes play important roles in determining seasonal to annual variations in patterns of habitat use, ecosystem structure (see examples in DFO 2006), and recruitment variations of salmon in the QCB.

4.5 Ecologically or Biologically Significant Areas (EBSAs) for Salmon in PNCIMA

The species and impressive life history diversity documented for Pacific salmon have allowed them to utilize a broad range of habitats that define both a large aquatic management area (LAMA) and a large oceanic area within PNCIMA. Salmon habitats of the LAMA extend from the interior of major river basins such as the Skeena, the Nass, and the Bella Coola through the medium sized rivers, lakes, and small streams of a significant portion of the watersheds lying west of the Coast Mountains to watersheds scattered throughout the Queen Charlotte Islands and the northern end of Vancouver Island. Salmon habitats of the oceanic area encompass marine waters of Johnstone Strait on the southern end of PNCIMA through the coastal fjords and inlets plus the broad continental shelf comprising Hecate Strait and Queen Charlotte Sound to Dixon Entrance in the north. As noted earlier, an average of 25-30 million adult salmon return to spawn annually in the watersheds of the PNCIMA area. Assuming an all-year, average, marine survival rate of roughly 4% among all species of juvenile salmon from the time of sea entry to return as adults (Bradford 1995) suggests that 625-750 million juvenile salmon may enter PNCIMA from its tributary watersheds each year. In addition to this, it is likely that, in aggregate, more than twice this many adult and juvenile Pacific salmon originating from or returning to more southerly coastal watersheds (*e.g.,* those of Georgia Basin, Puget Sound, Fraser Basin, coastal Washington, Oregon, and California) pass through PNCIMA coastal waters.

Although the detailed migratory routes and timing variations of individual stocks and species are known in only the most general terms, it is clear that key zones of egress and ingress (potential EBSAs) may be initially identified in association with the watersheds within PNCIMA that support the largest populations of salmon (Figures I.2a-f). The distribution and abundance of spawning salmon may be used as a crude, first approximation of the relative importance of key marine zones in PNCIMA for actively migrating juvenile and adult salmon. Thus, the waters of Dixon Entrance are a key zone that hosts annual migrations of large populations of migratory juvenile and adult salmon originating from large river systems such as the Nass and Skeena. In addition, coastal areas proximal to the Bella Coola and Atnarko rivers or Smith and Rivers inlets north of Johnstone Strait may be considered to be especially important potential EBSAs. Similarly, Johnstone Strait and Dixon Entrance are obvious areas of high sensitivity because salmon migratory behaviours, ocean currents, and coastal landforms combine to disproportionately concentrate juvenile and adult salmon originating from watersheds to the south as they pass through PNCIMA waters on their northward migrations in spring and southern migrations in summer through fall respectively. For salmon species such as coho and chinook that are more likely to reside for prolonged periods in PNCIMA, areas of high biological production near banks and shoals will serve to attract aggregations of rearing juveniles and so may be regarded as especially sensitive to disturbance. For example, there is evidence that the shoal-region centered on Juan Perez Sound on the southeast side of Moresby Island is a "hot spot" for biological production for many species in the southern QCB (Royal Society of Canada 2004) and thus it is not unexpected that several species of juvenile salmon also concentrate in this area (Figure I.8).

5.0 ECOSYSTEM LINKAGES FOR SALMON

5.1 Large Aquatic Management Area (LAMA)

The coastal strip of PNCIMA between Knight (lower Area 12, Figure I.6a) and Portland inlets (Area 3, Figure I.6a) has been called one of the few remnants of fully functioning rainforest in North America (McAllister *et al.* 1997; BC Coast Information Team 2004). Large populations of grizzly bears (BC government estimates of between 1500 and 3000; BC Coast Information Team 2004) along with 230 bird species, 68 species of mammals and thousands of insect species define a wildlife complex and level of biodiversity that ranks high enough among global sites for biodiversity that it has been compared to Africa's Serengeti Ecosystem (Reimchen pp. 93-96 in Harvey and MacDuffee 2002).

Ecological theory holds that certain animals exert a disproportionate influence on the ecosystems in which they live. Paine (1969) introduced the term "keystone species" to describe animals that, through their activities and abundances, regulate the productivity, diversity, or physical structure of their communities, with influences extending beyond those organisms directly affected through trophic interactions. Implicit in the concept is that keystone species are exceptional in their importance relative to the rest of the community (Mills *et al.* 1993), that they are unique in their functioning within the community, and that their impacts are disproportionately large relative to their abundances (Power *et al.* 1996). Loss of a keystone species results in significant changes in the structure or organization of a given ecosystem, with adverse consequences for the survival of other native species or populations (Helfield and Naiman 2006). Pacific salmon are commonly regarded as a keystone species in coastal ecosystems because of their importance as a limiting food resource for a diverse assemblage of vertebrate predators and scavengers (Willson and Halupka 1995; Willson *et al.* 1998; Cedarholm *et al.* 2000) and because of their importance as delivery agents for scarce nutrients (*e.g.*, phosphorus and nitrogen; Gresh *et al.* 2000) that commonly limit production at the base of the food-web in freshwater ecosystems throughout the eastern Pacific Rim including the LAMA (Stockner and Shortreed 1985; Hyatt and Stockner 1985; Hyatt *et al.* 2004a; 2004b).

Spatial and temporal variations in the abundance of spawning salmon can have major effects on the dynamics of wildlife populations and on maintenance of regional biodiversity (Willson and Halupka 1995). For example, Cedarholm *et al.* (2000) documented over 137 species of vertebrates, in addition to many invertebrates, which use salmon as a food source. Studies of ecological interactions between salmon and bears demonstrate just how critical these interactions with wildlife may be. Studies of southeast Alaskan coastal brown bears suggest that almost all of their carbon and nitrogen is obtained from salmon and that a correlation exists between the autumn mass of female bears and their reproductive success (Hildebrand *et al.* 1996). Consequently, it is not surprising that when sockeye salmon populations in the Rivers Inlet area of the LAMA virtually collapsed in 1999 that both grizzly and black bears were observed to be starving and several had to be shot as nuisance animals after their fall salmon food supply failed to appear (S. Bachen, DFO, Campbell River, pers comm., 2000). Indeed, the generally greater abundance of salmon appears to be the main reason for the maintenance of much higher densities of carnivores and scavengers in coastal as opposed to interior ecosystems (*e.g.*, bears are 6-80 times more abundant on the coast, Miller *et al.* 1997; see also Reimchen 2000).

The impact of large numbers of salmon returning to spawn in coastal ecosystems is not limited to just their direct consumption by carnivores and scavengers. Stable isotope analyses of sediment cores from Alaskan lakes (*e.g.*, Finney *et al.* 2000; Gregory-Eaves *et al.* 2003) have provided results to suggest that variations in sockeye salmon escapement and carcass deposition have a long term impact on variations in phosphorous (P) and nitrogen (N) delivery that influence subsequent variations in the productivity of nutrient poor lakes. Similarly, stable isotope analyses of plant communities adjacent to spawning streams suggest that riparian plants may derive as much as 18-60% of their foliar N from marine derived nutrients (MDN) imported from the high seas by spawning salmon (reviewed in Nelitz *et al.* 2006). Accordingly, variations of salmon returns in both space (Figures I.2a-f) and time (Figure I.4) will not only influence aquatic ecosystems throughout the LAMA but will also have significant effects on the structure, growth, and productivity of riparian vegetation (Naiman and Latterell 2005).

Naiman and Latterell (2005) have provided an initial synthesis of how interactions between carnivores/scavengers and salmon may affect the cycling of MDN to shape not only river and riparian ecosystems but also the long term viability of the contributing salmon populations. Adapting their work here (Figure I.9), bears and other piscivores consume Pacific salmon, spreading salmon-enriched wastes and partially-eaten carcasses into freshwater and riparian-zone habitats. Terrestrial and aquatic insects colonizing the carcasses enhance decomposition and diffusion of MDN. In the riparian forest, MDN are first re-mineralized by bacteria and then taken up by vegetation, increasing foliar N content and growth rates. Large riparian trees provide bank stabilization, shade, inputs of organic matter, and large woody debris (LWD) thus improving the quality of instream, salmon habitat. LWD retains post-spawn, salmon carcasses in streams, further enhancing MDN availability. Increased foliar N content enhances palatability and nutrition of riparian plants, potentially altering patterns of browsing by wildlife. This may affect patterns of riparian plant productivity and species composition. The net result is a positive feedback loop that enhances the strength of ecosystem linkages, ecosystem-scale productivity, and biodiversity (Figure I.9) as long as keystone interactions between bears and salmon remain functional. By contrast, external events that result in major reductions of salmon and/or bears (*e.g.*, climate induced mortality or harvest of one or both) have the potential to disrupt many of these processes, thus weakening ecosystem linkages (Figure I.9) and ultimately the feedback effects these have on ecosystems, salmon, and bears.

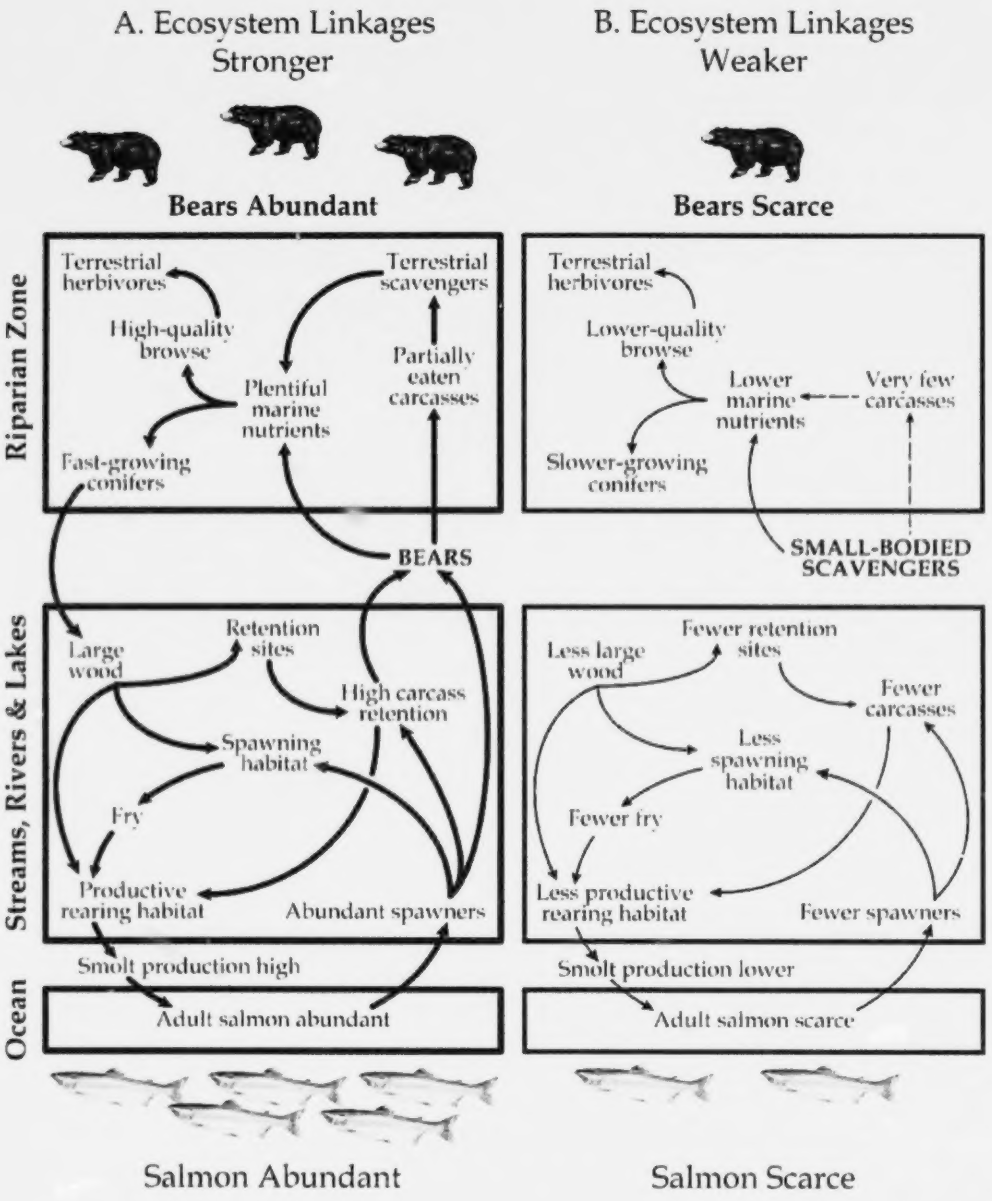

A. Ecosystem Linkages Stronger
B. Ecosystem Linkages Weaker
Bears Abundant
Bears Scarce
Riparian Zone
Streams, Rivers & Lakes
Ocean
Terrestrial herbivores
High-quality browse
Plentiful marine nutrients
Fast-growing conifers
Terrestrial scavengers
Partially eaten carcasses
BEARS
Large wood
Retention sites
High carcass retention
Spawning habitat
Fry
Productive rearing habitat
Abundant spawners
Smolt production high
Adult salmon abundant
Terrestrial herbivores
Lower-quality browse
Lower marine nutrients
Very few carcasses
Slower-growing conifers
SMALL-BODIED SCAVENGERS
Less large wood
Fewer retention sites
Fewer carcasses
Less spawning habitat
Fewer fry
Less productive rearing habitat
Fewer spawners
Smolt production lower
Adult salmon scarce
Salmon Abundant
Salmon Scarce

Figure I.9 A conceptual summary of the interactions among salmon and bears, acting as keystone species, in freshwater and riparian ecosystems of PNCIMA. A. Ecosystem linkages among many elements are strengthened when both salmon and bears are abundant; and B. Ecosystem linkages become much weaker and, in some cases, may be severed if bears or especially salmon become scarce. See text for details (figure modified from Naiman and Latterell 2005).

Anadromous salmon may act as important agents for delivery of critical nutrients (*e.g.*, phosphorus, nitrogen, and trace minerals) that control production at the base of food webs in many watersheds (Gresh *et al.* 2000), but this role is unlikely to be of uniform importance in all watersheds. Although inorganic phosphorus is known to commonly limit primary production by algal communities in coastal streams, rivers, and lakes (Stockner and Shortreed 1985; Hyatt and Stockner 1985; Hyatt *et al.* 2004b), examination of regional distributions of total dissolved solids in hundreds of aquatic habitats suggests that the distribution of nutrients, including inorganic phosphorous, is not uniform throughout the LAMA (Figure I.10). Thus, watersheds aggregate into clusters that exhibit varying levels of nutrient concentrations supporting a range of inherent productivity differences at sub-regional scale. Watersheds clustered in the area of Pitt, Banks, and Princess Royal islands bordering the central portion of the mainland of the LAMA appear to be especially nutrient poor (Figure I.10) while those clustered in the headwaters of the Dean, Bella Coola, Nimpkish (N. Vancouver Island), and Yakoun (QCI) rivers appear somewhat less nutrient impoverished (see Hyatt *et al.* 2004a; 2004b). These patterns may be explained in terms of differences in regional bedrock geology which, in combination with the erosive forces of weathering, influence annual to seasonal patterns of inorganic nutrient and mineral loading within various watersheds of the LAMA. Thus, the watersheds exhibiting higher total dissolved solids (TDS) values noted above (*e.g.*, the Dean, Bella Coola, Yakoun, Nimpkish, etc.) are underlain by mixtures of sedimentary and volcanic rock which provide higher inorganic nutrient concentrations than those present in other coastal watersheds (*e.g.*, Princess Royal, Pitt, and Banks) dominated by nutrient poor, granitic rock and crystalline gneiss (Farley 1979, p.29).

These differences alone help explain, in part, why the long term production of all salmon originating from the Pitt, Banks, and Princess Royal Island area watersheds is lower than the aggregate production observed in other areas of similar size (Figures I.2a-f). In theory, this may be relevant to interagency responsibilities for maintenance of regional biodiversity in this portion of the LAMA where the government of BC recently designated selected watersheds in and around Princess Royal Island as the Kitasoo Spirit Bear Protected Area (February 2006) for conservation of culturally significant Kermode bears (Russell 1994; McAllister *et al.* 1997). These observations are significant to the development of ecosystem based management principles for application to wild salmon populations because they indicate that the disruption of nutrient delivery by salmon to watersheds due to commercial harvest of salmon will involve a range of consequences that may vary in severity from area to area depending on a host of interacting factors (see also Gresh *et al.* 2000; Nelitz *et al.* 2006).

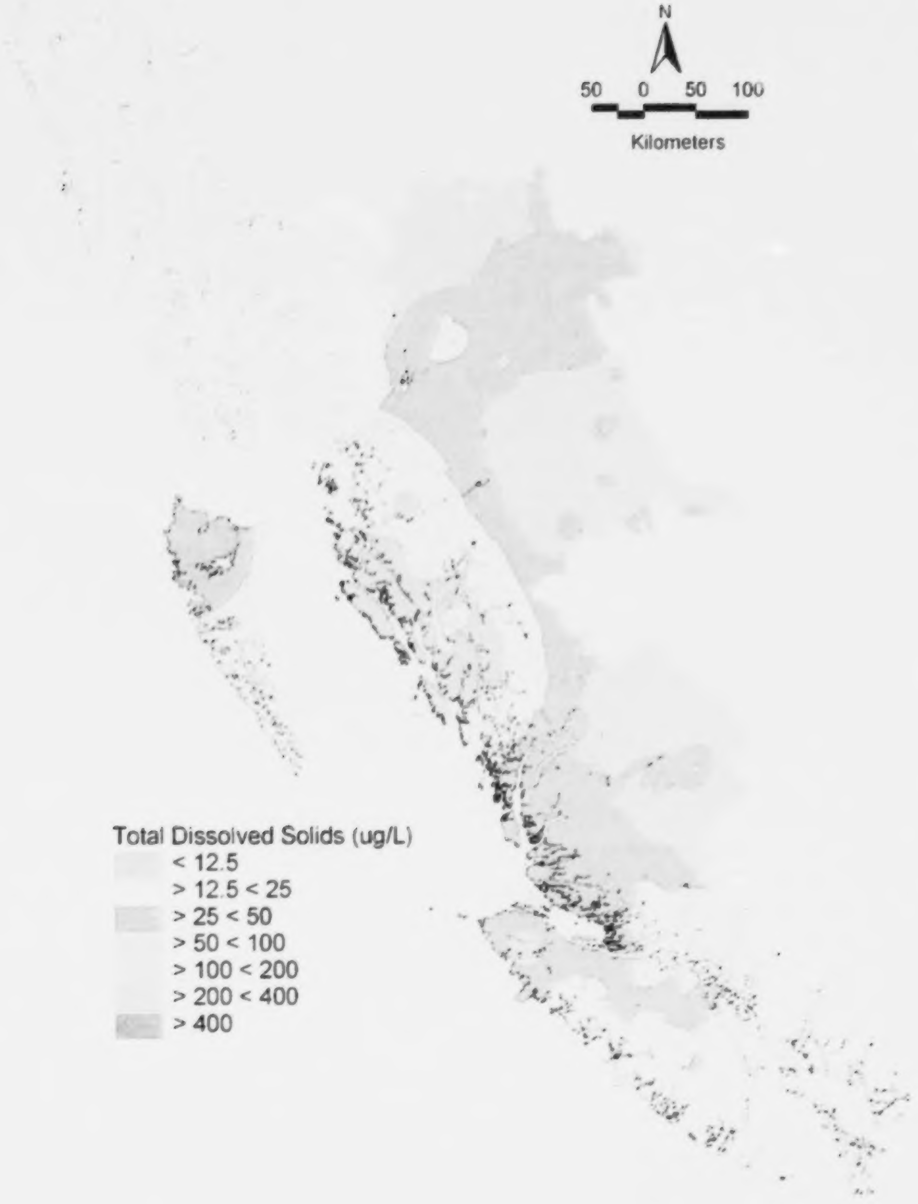

N
50
0
50
100
Kilometers
Total Dissolved Solids (ug/L)
< 12.5
> 12.5 < 25
> 25 < 50
> 50 < 100
> 100 < 200
> 200 < 400
> 400

Figure I.10 A summary of spatial patterns of total dissolved solids (TDS) present in freshwater rivers and streams sampled in hundreds of locations throughout the PNCIMA portion of British Columbia. Note unequal classification intervals from the low to high end of the scale. TDS observations from BC Ministry of Environment. TDS categories and figure format developed by Hyatt *et al.* (this report).

5.2 Queen Charlotte Basin (QCB)

Long term (1900-2000) average catches of all salmon species in the QCB amount to less than 30,000 tonnes yr^{-1} (Figure I.5). Given that catches of salmon throughout this interval have, on average, amounted to no more than 50% of production, it would appear that total salmon biomass originating in the QCB amounts to no more than 60,000 tonnes per year. Furthermore, the latter figure may not fairly represent the quantity of Pacific salmon actually produced in the QCB because: (1) sockeye, pink, and chum salmon, by far the most abundant species, spend the majority of their lives in offshore pelagic waters of the Gulf of Alaska and only relatively brief periods rearing in coastal areas of the QCB as much smaller juveniles and returning adults; and (2) a portion of the salmon catch landed by commercial fisheries in the QCB consists of interceptions of southern stocks migrating through the area (*e.g.*, Fraser R., mainland inlets, west coast Vancouver Island).

By contrast, Ware and McFarlane (1989) noted that resident stocks of chinook and coho salmon in the QCB portion of the Coastal Downwelling Domain accounted for less than 35 tonnes of biomass while herring stocks alone accounted for an average biomass of nearly 180,000 tonnes. Thus, Pacific salmon do not function as ecological keystone species in marine environments of the QCB to the extent that they do in freshwater and hydroriparian ecosystems of the LAMA noted above. This is not to say that Pacific salmon are unimportant in marine ecosystems but rather that their importance is more likely to depend on the occurrence of specialized ecosystem linkages to other marine species (*e.g.*, Cedarholm *et al.* 2000) rather than as a causal agent of more systemic ecosystem processes. For example, Ford *et al.* (1998) have noted that from April to October, resident orcas (*Orcinus orca*) congregate in areas such as Johnstone Strait at times that correlate with seasonal salmon migrations. Further, these authors speculate that specialized foraging strategies have developed within specific pods of whales to correlate with various salmon runs and species (*e.g.*, especially chinook salmon) that, in turn, may determine the long term well being of particular groups of whales.

Although Pacific salmon do not serve as keystone species in the QCB from an ecological perspective, there remains no doubt about their keystone role there from a cultural perspective (*in sensu* Garibaldi and Turner 2004). Given their cultural and economic importance in large ocean management areas, salmon are generally regarded as very important, but complex, indicators of the effects of both natural and man-made disturbances that may create multiple stressors on ecologically and biologically sensitive areas (*e.g.*, EBSAs including points of seaward entry, principal migration corridors, rearing areas, etc.) as well as serving as focal point subjects themselves for biological conservation and sustainable resource use. The latter items in particular have increasingly become focal points for fisheries and species management issues in many regions of the QCB as contemporary fisheries management objectives have evolved from an historic emphasis on maximizing biomass of single species harvest to a more recent emphasis on minimizing loss of biodiversity among multi-species assemblages of commercially exploited Pacific salmon stocks (Hyatt and Riddell 2000). For example, decades of concern over significant bycatch of steelhead salmon (*O. mykiss*) in large commercial fisheries for sockeye salmon (*O. nerka*) in approaches to rivers such as the Skeena and Nass have translated into increasingly stringent area and time constraints on sockeye fisheries to protect the much less abundant stocks of steelhead (Sprout and Kadowaki 1987). Even more recently, additional area and time constraints have been applied to harvest of highly productive sockeye stocks returning to Babine (Skeena R.) and Meziadin (Nass R.) lakes to facilitate conservation and rebuilding of dozens of small, but genetically distinct, sockeye populations that occur as complex mixtures in salmon fisheries throughout the northern portion of the QCB (Fisheries and Oceans Canada 2006).

6.0 ISSUES AND INFORMATION GAPS

Pacific salmon are at once the subjects of one of the most advanced as well as one of the most cumbersome systems of fisheries management anywhere on the globe. Scores of fisheries harvest salmon from hundreds to thousands of populations in PNCIMA alone and have done so for anywhere from a century (contemporary fisheries) to thousands of years (aboriginal fisheries). In spite of this enviable record of success, there are signs that significant changes are required in current-day management practices in order to ensure the long-term sustainability of the salmon stock-and-habitat complex of PNCIMA. Fisheries and Oceans Canada's new Wild Salmon Policy (WSP; Fisheries and Oceans Canada 2005) identifies a general blueprint for achieving this general goal by focusing DFO and societal efforts on three major objectives, six strategies, and four guiding principles (Figure I.11). Although detailed review of the WSP is not warranted here, a cursory examination will suffice to suggest the types of important issues and information concerns that emerge when considering its application to the salmon stock-and-habitat complex of PNCIMA, as follows.

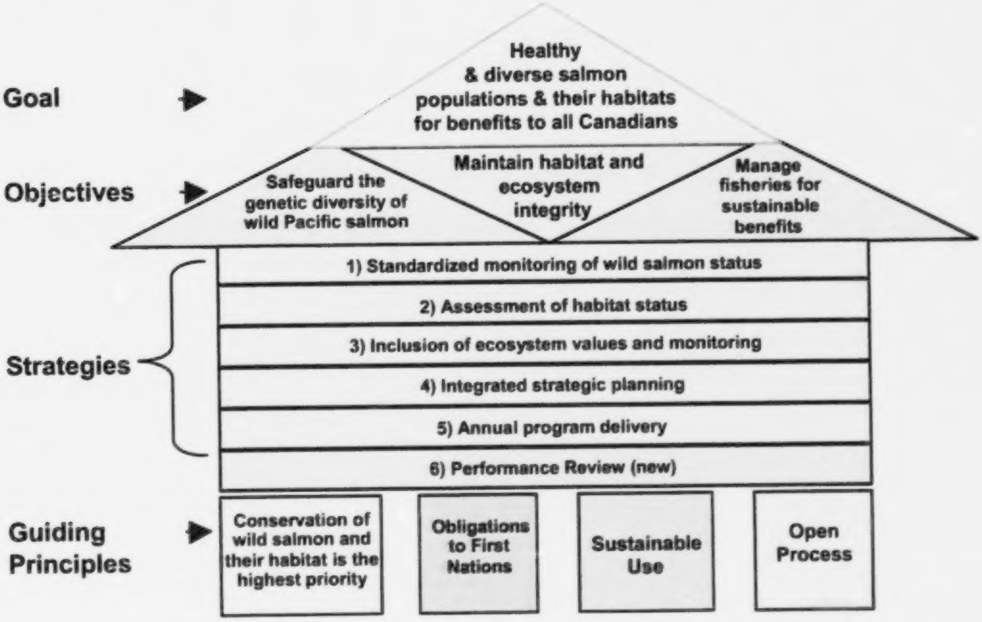

Goal
Healthy & diverse salmon populations & their habitats for benefits to all Canadians
Objectives
Safeguard the genetic diversity of wild Pacific salmon
Maintain habitat and ecosystem integrity
Manage fisheries for sustainable benefits
Strategies
1) Standardized monitoring of wild salmon status
2) Assessment of habitat status
3) Inclusion of ecosystem values and monitoring
4) Integrated strategic planning
5) Annual program delivery
6) Performance Review (new)
Guiding Principles
Conservation of wild salmon and their habitat is the highest priority
Obligations to First Nations
Sustainable Use
Open Process

Figure I.11 Structure of Fisheries and Oceans Canada's Wild Salmon Policy including its overarching goal along with specific objectives, strategies, and guiding principles for implementation (adapted from Fisheries and Oceans Canada 2005).

Objective 1 of the WSP (Fisheries and Oceans Canada 2005) is to safeguard the diversity of wild Pacific salmon. Thus DFO intends to maintain the genetic diversity of Pacific salmon through the protection of Conservation Units (CUs) that represent a group of wild salmon sufficiently isolated from other groups that if extirpated is very unlikely to recolonize naturally within an acceptable timeframe (*e.g.*, a human lifespan). Earlier in this report it was noted that different species of salmon display large differences in their genetic affinities such that the number of wild salmon CUs in PNCIMA will vary from hundreds in the case of sockeye, where every lake and river combination will contain a CU, to less than a dozen in the case of pink or coho salmon, where high rates of straying create large, meta-populations of genetically related individuals that simultaneously occupy many streams and rivers spread across appreciable portions of major watersheds (*e.g.*, Upper Skeena). Thus, CUs represent a new conservation focal point around which resource management and stock assessment must be organized. In PNCIMA this is problematic given that historic stock assessments have failed to generate sufficient information to classify the status of more than 40% of all local salmon populations (Slaney *et al.* 1996) including at least 51 of 117 sockeye populations (Riddell 2004) that are likely to be CUs under the WSP. In addition, both the Pacific Fisheries Resource Conservation Council (PFRCC 2005) and other independent observers (Thomson and MacDuffee 2002) noted declines in assessment effort from the 1980s to present to survey salmon populations throughout PNCIMA. Both of the latter studies stressed that historical spawner abundance surveys and data are the base for any future assessments and development of sound conservation strategies.

Objectives 2 and 3 of the WSP are to maintain habitat and also ecosystem integrity because, as described earlier in this chapter, the health and well-being of wild salmon is inextricably linked to the availability of a diversity of interconnected and productive freshwater and marine habitats used by each of the several species throughout PNCIMA. Aquatic habitats and their adjacent terrestrial areas are also valued for a wide range of human activities. Consequently, the integrity of salmon habitat is challenged by human competition for accessible land and fresh water, for ocean spaces and for the interconnecting estuarine and coastal areas that may be utilized for a variety of activities including: urban development, large scale resource extraction, aquaculture, or the industrial-scale manufacture of goods. Given a total human population of less than 100,000 (Prescott-Allen 2005), the sum of these activities in PNCIMA is currently modest by comparison with the state of habitat and ecosystem disruption in salmon bearing systems to the south of PNCIMA (Slaney *et al.* 1996). However, there is a growing appreciation that the relatively undisturbed state of natural ecosystems in PNCIMA has the potential for very rapid change within 1-2 decades in the face of a variety of ecological threats that include: commercial fisheries, accelerating industrial forestry (Harvey and MacDuffee 2002), development of oil and gas resources (Royal Society of Canada 2004), aquaculture development (PFRCC 2002), increased tourism, and outside disturbances such as climate change (Government of British Columbia 2006).

In addition to the obvious threats that human activities pose for the maintenance of productive habitat for Pacific salmon, there is a growing body of credible scientific evidence to suggest that maintenance of habitat and ecosystem integrity also involves a positive feedback loop in which habitat structure and ecological processes are dependent on multiple influences of the salmon themselves (Figure I.9). Consequently, salmon harvest levels, once considered to be a relatively simple exercise involving the removal of adult fish that were surplus to requirements for "seeding" the next generation of returns (*e.g.*, Ricker 1954), have become the focus for debates about tradeoffs between the immediate socioeconomic benefits of harvest versus the longer term ecological benefits of foregoing harvest to maintain key elements of regional biodiversity, habitat productivity, and ecosystem integrity. Thus, Reimchen (pp. 93-96 in Harvey and MacDuffee 2002) has argued that average exploitation rates on salmon are 3-20 times those observed in most natural, multi-predator species communities and suggests that a long term, sustainable harvest rate should not exceed 5% for individual salmon populations!

Although opinions such as Reimchen's may seem unnecessarily Draconian, they do serve to underscore the fact that salmon management has entered a period of increasingly complex and, oftentimes, competing objectives that are unlikely to be satisfied by traditional single species yield or assessment frameworks (Hyatt and Riddell 2000; see also pp. 72-79 of Cedarholm *et al.* 2000). Similarly, spatial and temporal interactions that depend not only on the state of salmon habitat but also on the influence that salmon may exert on the long-term productive capacity of these habitats suggests that the common practice of conducting salmon stock or salmon habitat assessments rather than assessments of the salmon stock-habitat complex will be increasingly inadequate as a basis for sustainable management of Pacific salmon in the future. Reflecting on what this implies about future assessment frameworks to improve management, Cedarholm *et al.* (2000) concluded that managing salmon as keystone species within an ecosystem context will require material, energy, and nutrient budget analyses on appropriate spatial (*e.g.*, PNCIMA, major river basin, sub-basin, stream) and temporal (months to millennia) scales to estimate the effects that land and fisheries resource management practices (past, present, future) have on ecosystems and salmon populations, and that the latter have on ecosystems. Questions that may be posed as relevant to the pursuit of this objective include: (1) what is the status of the inorganic nutrient capital and rates of transport that limit habitat productivity within the various domains of salmon (inorganic nutrient budget)?, (2) what is the range of the organic nutrient and materials capital and rates of transport (how does the current budget relate to the known range of standing stocks, rates of metabolism, and transport for salmon)?, (3) how have humans altered nutrient budgets?, (4) what adaptive management actions might be warranted and feasible with respect to salmon and nutrient cycling to push terrestrial and aquatic systems toward desirable goals?, and (5) what are the desired future conditions?

The WSP explicitly recognizes the need to treat salmon and their habitats or ecosystems as integrated entities for assessment and management. However, it also acknowledges a limited ability to immediately incorporate a wide range of ecosystem values and principles into salmon management given the complexity of the types of questions posed above and a limited experience in designing, implementing, and supporting ecosystem based management (EBM) frameworks. Regardless, it is obvious that the breadth and complexity of issues that must be engaged to ensure prudent management for the long term sustainability of the salmon stock-and-habitat complex recommends much greater research and management efforts on this front.

The development of an effective EBM framework to ensure sustainability of the salmon-and-habitat complex over the expanse of geography as large as PNCIMA represents an enormous challenge. However, a considerable body of information and experience with developing EBM frameworks to facilitate natural resource and land use management in PNCIMA has already been developed by the government of BC, among others, through the activities of an independent Coast Information Team (CIT) to consider land and resource management planning (LRMP) in PNCIMA from an EBM perspective (BC Coast Information Team 2004). The CIT's task was to produce information to help governments and participants in land and resource planning processes reach decisions that achieved ecosystem based management. The efforts of the CIT were clearly not focused on the full range of salmon management issues (*e.g.*, those identified in this chapter or by the WSP) and consequently both the content and implementation of their EBM approach has been criticized (Paquet *et al.* 2004). Nonetheless, CIT activities have clarified many of the future requirements for EBM in PNCIMA and provide a foundation[1] that may be built upon to meet WSP objectives related to conservation, habitat protection, and ecosystem based management of Pacific salmon within PNCIMA.

7.0 GLOSSARY

Advection Zone – An area of horizontal, large scale movement of seawater.

Anadromous – Fish species that spawn (breed and lay eggs) in freshwater environments, but spend at least part of their adult life in a seawater environment.

Coastal Downwelling Domain (CDD) – One of three major fisheries production areas in the northeast Pacific Ocean (including: Coastal Upwelling Domain and the Central Sub-Arctic Domain; Ware and McFarlane 1989). The Coastal Downwelling Domain encompasses the coastal waters extending from Queen Charlotte Sound to the Aleutian Islands. The circulation pattern is dominated by the counter clockwise flowing Alaska Current.

Ecosystem based management – Ecosystem based management has been defined as "an adaptive approach to managing human activities that seeks to ensure the coexistence of healthy, fully functioning ecosystems and human communities. The intent is to maintain those spatial and temporal characteristics of ecosystems such that component species and ecological processes can be sustained, and human well-being supported and improved." (Excerpted from the CCLCRMP Framework Agreement/Draft Interim Plan, Coast Information Team Document called Ecosystem based Management Framework, April 2004).

Epibenthic – Refers to the area on the top of the sea floor. Epibenthic organisms may be freely moving or sessile (permanently attached to a surface).

Fidelity – "Homing fidelity" is the propensity for adult salmonids to return to their natal freshwater spawning grounds following maturation at sea.

Isobaths – A contour (or surface) of equal depth in a body of water.

Morphological – Refers to structure or form.

Pacific Decadal Oscillation (PDO) – A pattern of climate and ocean condition regimes occurring in the north Pacific Ocean (associated with the Aleutian low pressure system) that results in shifts in sea surface temperatures and plankton abundance on a decades-long time scale.

Paleoclimate – Climate for periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available.

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[1] For details readers may wish to consult the CIT EBM Planning Handbook, the Hydroriparian Planning Guide, the Scientific Basis of EBM, and the Policy and Institutional Analysis for more in-depth elaboration of the EBM Framework. All CIT documents are available for downloading from the CIT Web site at www.citbc.org

Paleoecological – The ecological interaction between ancient organisms and their environment.

Redd – A nest prepared by a female fish in the stream bed gravel, stones, or sand, where she deposits her eggs.

Riparian – A zone of transition from an aquatic to a terrestrial system, dependent upon surface or subsurface water. A riparian area may be located adjacent to a lake or estuary, as well as an ephemeral, intermittent, or perennial stream or creek.

Upwelling – A process in which cold, often nutrient-rich waters rise to the surface.

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Canadian Technical Report of
Fisheries and Aquatic Sciences 2667

2006

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX J: MARINE MAMMALS AND TURTLES

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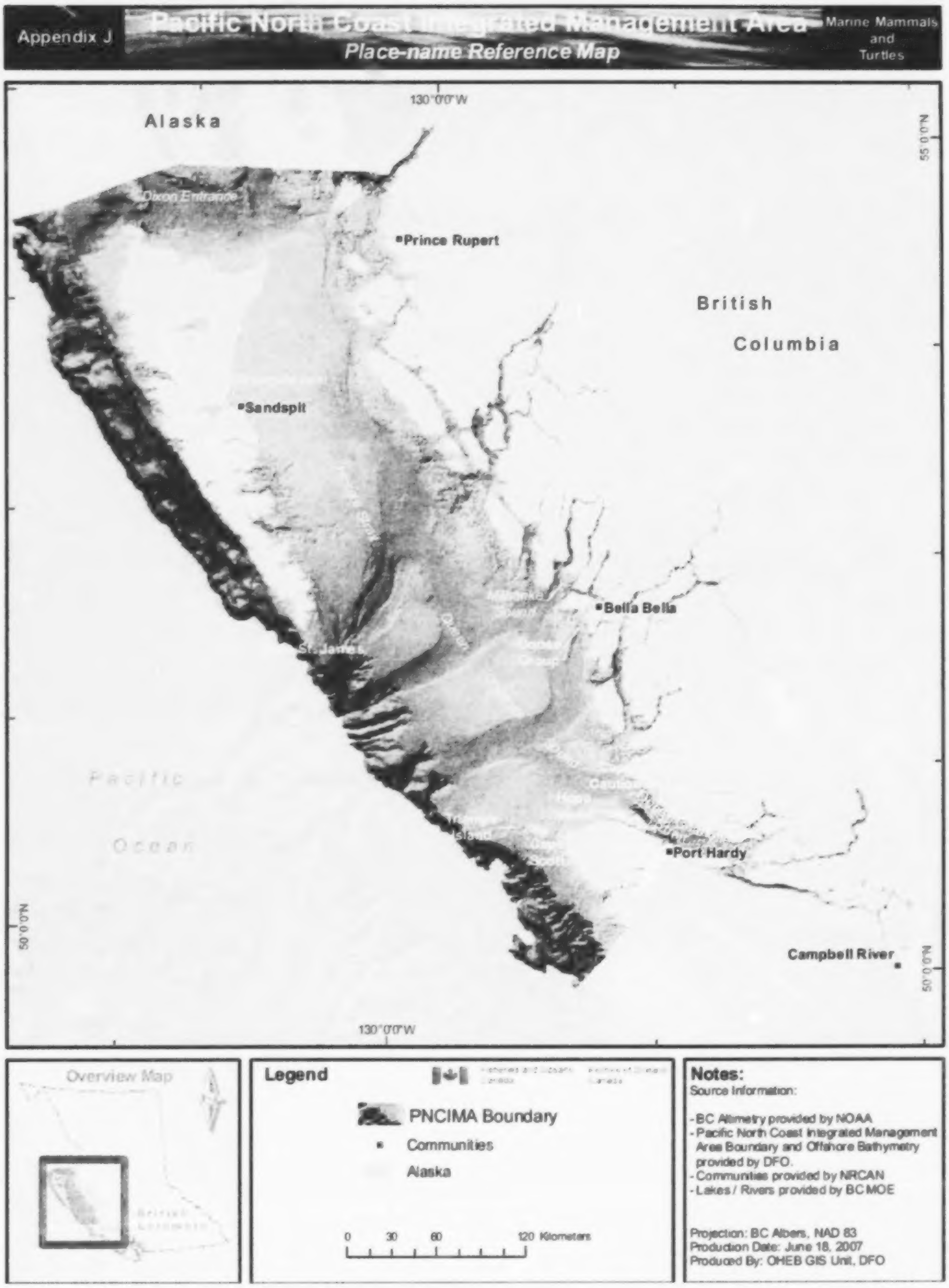
1.0 INTRODUCTION

Marine mammals, which include baleen and toothed whales, pinnipeds and sea otters, are an important component of the Pacific North Coast Integrated Management Area (PNCIMA; Figure J.0) ecosystem. We also include marine turtles here because they share some of the same life history traits with those of marine mammals. Within the group there is an incredible diversity of life history strategies, and species range from high trophic level predators that are present year round to low trophic level predators that are present seasonally. Detailed information on abundance, distribution, population trends, critical habitat, and ecosystem linkages is lacking for many species.

We present here a list of the species that are known to occur within PNCIMA, a brief description of their use of the area, diet, estimated current population size and COSEWIC status (Table J.0). For species for which information is available, we provide a timeline of their presence within PNCIMA (Table J.1). Following these tables, a brief summary of the biology, management status, threats, and additional reference material are provided for COSEWIC designated species, as well as for some of the more common species within PNCIMA ecosystem.



Appendix J
Pacific North Coast Integrated Management Area
Place-name Reference Map
Marine Mammals and Turtles
130°0'0"W
55°0'0"N
Alaska
Dixon Entrance
Prince Rupert
British
Columbia
Sandspit
St. James
Bella Bella
Pacific
Ocean
Port Hardy
Campbell River
50°0'0"N
Overview Map
British Columbia
Legend
PNCIMA Boundary
Communities
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
-BC Altimetry provided by NOAA
-Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
-Communities provided by NRCAN
-Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure J.0 PNCIMA region showing locations and features of BC waters.

Table J.0 Marine mammals found within PNCIMA, their use of the area (*e.g.*, foraging, breeding), diet, current estimated population size, and COSEWIC status (modified from Johannessen *et al.* 2005).

Species	**Use of PNCIMA**	**Diet**	**Estimated Population**	**COSEWIC Status**
Baleen Whales				
Blue Whale	Not well understood. Historically generally offshore distribution, but occasionally in Hecate Strait. Use area for foraging and migration.	Euphausiids.	2,000-3,000 in eastern North Pacific	Endangered
Fin Whale	Not well understood, but historically present in many areas. Likely use area for foraging and migration.	Euphausiids, schooling fish, squid.	5,700 in eastern North Pacific	Threatened
Sei Whale	Not well understood. Historically generally offshore but occasionally in Hecate Strait and Queen Charlotte Sound.	Copepods primarily; also euphausiids, fish, squid.	35 in eastern North Pacific	Endangered
Minke Whale	Not well understood but likely year round resident, most frequently found in nearshore waters.	Schooling fish.	Unknown but not abundant; <600 in CA/OR/WA	Not Assessed
Humpback Whale	Frequently seen. Use area for foraging and migration.	Euphausiids primarily; also copepods, small fish.	1,500 in BC; 6,500 in eastern North Pacific	Threatened
Gray Whale	Frequently seen. Use area for foraging and migration, especially from April-June and Dec-Jan. Some whales remain resident throughout summer to forage.	Herring eggs/ larvae, mysids, crab larvae, amphipods, ghost shrimps.	18,800 in eastern North Pacific	Special Concern
North Pacific Right Whale	Very little is known, but were historically present. Now extremely rare due to over-exploitation. May return to area if North Pacific population recovers in other areas.	Copepods.	<300 in eastern North Pacific	Endangered
Toothed Whales				
Sperm Whale	Not well understood, generally offshore but males move further inshore in summer to feed. Calving may occur offshore.	Fish and squid.	Unknown but 885 in CA/OR/WA	Not at Risk
Killer Whale - Northern Resident	Found year round. Forage and breed in the area.	Fish, especially salmon.	205	Threatened
Killer Whale - Transient	Found year round. Forage and breed in the area.	Marine mammals.	220	Threatened
Killer Whale - Offshore	Not well understood, but likely use the area for foraging and breeding.	Uncertain but likely fish.	250 identified to date	Special Concern
Killer Whale - Southern Resident	Occasionally in area, particularly NW Vancouver Island, likely for foraging.	Fish, especially salmon.	85	Endangered
Pacific White-sided Dolphin	Not well understood, but likely year round residents that use entire area for foraging and breeding.	Fish and squid.	Unknown but 26,860 in central North Pacific, 39,822 in CA/OR/WA	Not at Risk

Table J.0 Continued…

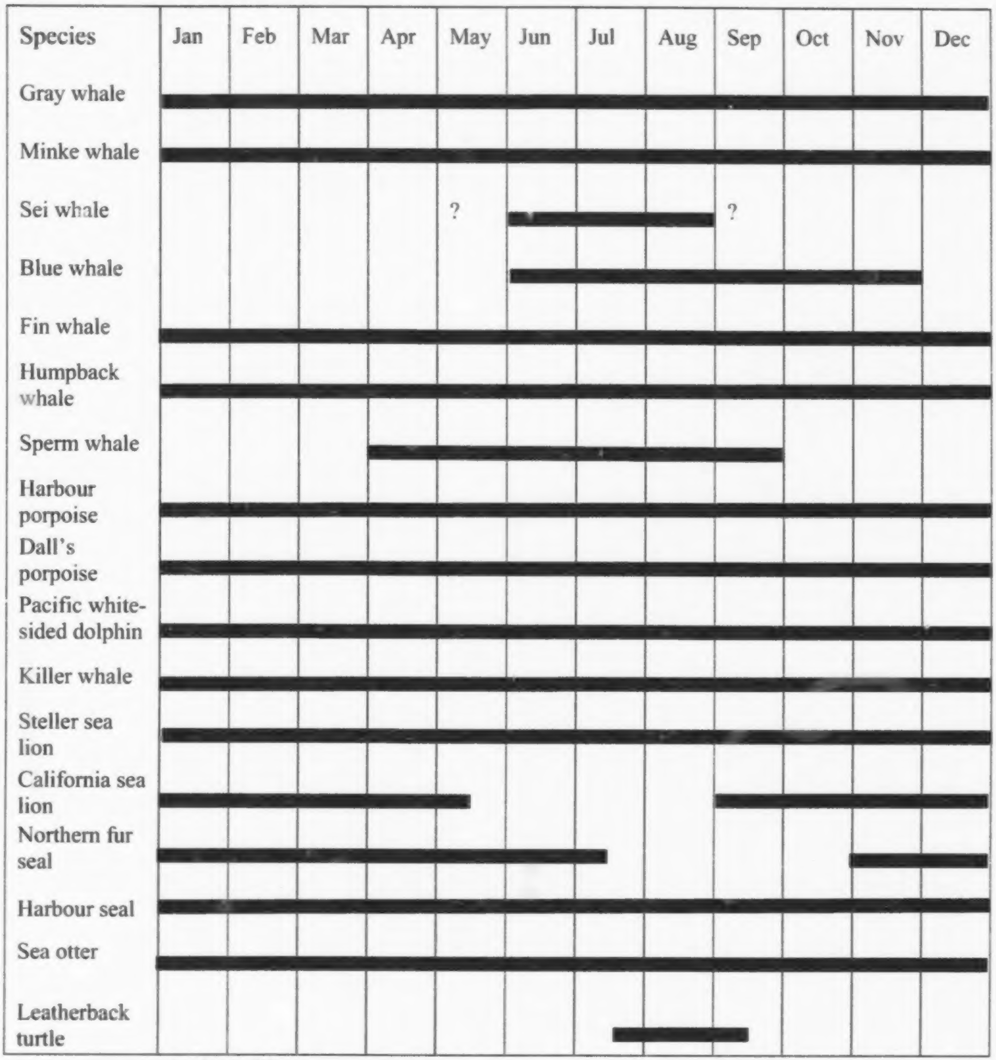
Species	Use of PNCIMA	Diet	Estimated Population	COSEWIC Status
Dall's Porpoise	Not well understood but year round residents that use area for foraging and calving.	Small fish and squid.	Unknown but 83,400 in Alaska, 75,915 in CA/OR/WA	Not at Risk
Harbour Porpoise	Not well understood but year round residents most commonly found in shallow (<200 m) nearshore areas.	Small fish and squid.	Unknown but 28,967 in WA/OR, 37,450 in southeast Alaska	Special Concern
Striped Dolphin	Rare visitor to area.	Fish, squid, crustaceans.	Unknown but 9,165 in CA/OR/WA	Not at Risk
Long-beaked Common Dolphin	Rare visitor to area.	Fish and squid.	Unknown but 25,000 in CA/OR/WA	Not at Risk
Risso's Dolphin	Uncommon visitor to area.	Fish and squid.	Unknown but 12,748 in CA/OR/WA	Not at Risk
Northern Right Whale Dolphin	Uncommon but occasionally found in large groups in offshore waters, often with Pacific white-sided dolphins.	Fish and squid.	Unknown but 16,417 in CA/OR/WA	Not at Risk
Short-finned Pilot Whale	Uncommon.	Fish and squid.	Unknown but 149 in CA/OR/WA	Not at Risk
False Killer Whale	Rare visitor to area.	Fish and squid.	Unknown	Not at Risk
Baird's Beaked Whale	Uncommon; generally found in waters >1000 m deep.	Fish and squid.	Unknown but 152 in CA/OR/WA	Not at Risk
Stejneger's Beaked Whale	Likely rare.	Unknown.	Unknown	Not at Risk
Hubb's Beaked Whale	Likely rare. Known only from stranding record near northern Vancouver Island.	Unknown.	Unknown	Not at Risk
Cuvier's Beaked Whale	Likely rare. Have been seen in Hecate Strait in recent years.	Cephalopods, fish, and crustaceans.	Unknown but 1,121 in CA/OR/WA	Not at Risk
Pinnipeds				
Steller Sea Lion	All 3 breeding rookeries in Canada within PNCIMA, and it supports important haul-out sites and foraging grounds for population.	Fish, cephalopods, and other invertebrates.	18,400-19,700 in BC	Special Concern
California Sea Lion	Males and sub-adults migrate north from CA in winter and small numbers occur in PNCIMA from September through May.	Fish, cephalopods, and other invertebrates.	1,500-3,000 in BC	Not Assessed
Harbour Seal	Year-round resident, ubiquitous throughout BC, and widely distributed within PNCIMA.	Fish, cephalopods, and other invertebrates.	108,000 in BC	Not at Risk
Northern Elephant Seal	Not well understood, but seals disperse widely to continental shelf and slope waters to forage, from winter breeding rookeries and moulting sites in Mexico and California.	Squid and fish.	101,000 in North Pacific	Not Assessed

Table J.0 Continued…

Species	Use of PNCIMA	Diet	Estimated Population	COSEWIC Status
Northern Fur Seal	Pelagic, winter off continental shelf and shelf break, and in spring migrate north along west side of Haida Gwaii and further offshore. Some overwinter in Hecate Strait and up inlets.	Fish and squid.	888,000 in North Pacific	Under Review
Others				
Sea Otter	Year round residents of central coast and often found in small groups off northern Vancouver Island. Use area for feeding and breeding.	Benthic invertebrates.	500 on central BC coast, 2700 off west coast of Vancouver Island	Threatened
Leatherback Turtle	Rare visitor July through September. Likely feed in area. Sightings have increased in recent years.	Soft-bodied invertebrates.	Unknown	Endangered

Source: (Flinn *et al.* 2002; Heise *et al.* 2003a; Angliss and Outlaw 2005; Carretta *et al.* 2005; Ford 2006; J. Ford unpublished data; P. Olesiuk, unpublished data).

Table J.1 Timeline of estimated or assumed seasonal presence of cetaceans, pinnipeds, and leatherback turtles in PNCIMA waters for species with available information (modified from Johannessen *et al.* 2005).



Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gray whale	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Minke whale	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Sei whale					?	▬	▬	▬	?			
Blue whale						▬	▬	▬	▬	▬	▬	
Fin whale	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Humpback whale	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Sperm whale				▬	▬	▬	▬	▬	▬			
Harbour porpoise	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Dall's porpoise	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Pacific white-sided dolphin	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Killer whale	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Steller sea lion	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
California sea lion	▬	▬	▬	▬	▬				▬	▬	▬	▬
Northern fur seal	▬	▬	▬	▬	▬	▬	▬				▬	▬
Harbour seal	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Sea otter	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Leatherback turtle							▬	▬	▬			

▬ Period of known occurrence.

Source: (Baird and Stacey 1989; Bigg 1990; John Ford unpublished data; Heise *et al.* 2003a; Olesiuk and Trites 2003; Olesiuk and Bigg 1988; Spaven and Ford 2006).

2.0 BALEEN WHALES

Seven species of baleen whales are found within PNCIMA, six of which are designated at risk by COSEWIC (Table J.0). They range in size from the smallest, the minke whale, to the largest, the blue whale. They generally feed on plankton and small fish. Some species, such as the humpback and the gray whale, migrate from warm low-latitude breeding areas through PNCIMA to higher latitude feeding areas in summer, although individuals from within populations may remain in PNCIMA throughout the summer or year round (*e.g.*, gray and humpback whales). The movements of other species, such as blue and fin whales, are less well understood.

Much of what we do know about baleen whales comes from the analysis of historical whaling records (Nichol and Heise 1992; Gregr *et al.* 2000; Flinn *et al.* 2002). Intensive commercial shore-based whaling took place in the area between 1910-1943, and 1948-1967 and has had long-term population-level consequences. Some populations, such as those of the eastern Pacific gray whale, have recovered, whereas others, such as the North Pacific right whale and the sei whale, remain critically endangered. The effects of commercial exploitation may have had far reaching consequences for the entire ecosystem. Springer *et al.* (2003) suggest that when large baleen whales were removed through commercial whaling, killer whales were forced to shift their prey base to smaller marine mammals, resulting in the collapse of several populations in western Alaska, including seals, sea lions, and sea otters. This hypothesis has not been widely accepted, however, and populations of small marine mammals in BC actually increased following the depletion of whales by whaling (Trites *et al.* 2006).

2.1 Blue Whale (*Baiaenoptera musculus*)

2.1.1 Basic Biology and Habitat

Length: up to 29.9 m Lifespan: >70 yrs

Blue whales are relatively rare within PNCIMA, and much of what is known about them comes from analyses of historical whaling records. Most were encountered in productive areas along the edge of the continental shelf and in the open Pacific as they migrated north to rich feeding areas during summer, or south as they returned to warmer waters for breeding. Peak catches from whaling were in June and September (Rice 1974). Analyses of stomach contents show that blue whales are low trophic level foragers that feed primarily on euphausiids (Nichol and Heise 1992).

Blue whales communicate using low frequency sound (12-200 Hz). Analyses of acoustic data suggest that there are at least 2 populations of blue whales in the North Pacific, an eastern North Pacific population and a central / western North Pacific population (Stafford *et al.* 1999). Hydrophones moored far off the west coast of Vancouver Island have detected eastern North Pacific blue whale calls offshore from August through March, although they are heard most consistently from October through February

(Burtenshaw *et al.* 2004). The BC Cetacean Sightings Network has recorded a number of sightings of blue whales within PNCIMA since 1972. Since the spring of 2002 there have been several sightings of blue whales made during biannual research cruises by Fisheries and Oceans Canada's (DFO's) Cetacean Research Program, mostly around Cape St. James, but also including a sighting in Hecate Strait midway between Triangle Island and Cape St. James (J. Ford, unpublished data). As sightings of blue whales are still relatively rare, much of the areas shown in Chapter 2 Map 2.17 reflects their historical distribution rather than current knowledge.

2.1.2 Management

Over 720 blue whales were taken from the region between 1910 and 1967 when commercial whaling ended (Nichol and Heise 1992). Since then, blue whales have been censused through line transect surveys and by individual photo-identification. Using these methods, the blue whale population is currently estimated at 2,000-3,000 for the eastern North Pacific (Calambokidis and Barlow 2004). DFO's Cetacean Research Program is currently undertaking surveys for blue whales within PNCIMA.

2.1.3 Additional Information Sources

COSEWIC. 2002. COSEWIC Assessment and Update Status Report on the Blue Whale *Balaenoptera musculus* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 32p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

Gregr, E., J. Calambokidis, L. Convey, J. Ford, I. Perry, L. Spaven, M. Zacharias. 2005. Draft Recovery Strategy for Blue Whales (*Balaenoptera musculus*), Fin Whales (*B. physalus*) and Sei Whales (*B. borealis*) in Pacific Canadian Waters. Fisheries and Oceans Canada. Nanaimo, BC.

2.2 Fin Whale (*Balaenoptera physalus*)

2.2.1 Basic Biology and Habitat

Length: 27 m Lifespan: >70 yrs

Fin whales are now relatively uncommon within PNCIMA, but were historically more common than blue whales, especially in Dixon Entrance and in the slope area between southern Haida Gwaii (Queen Charlotte Islands) and northwestern Vancouver Island (Chapter 2 Map 2.18). Fin whales also entered Hecate Strait and Queen Charlotte Sound and were taken in mainland inlets. Recent research cruises by DFO's Cetacean Research Program (2002-2006) found fin whales in similar areas, and they are present year round (J. Ford, unpublished data).

Historically, catches of fin whales were highest in July and August (Heise *et al.* 2003b). Pike and MacAskie (1969) suggested that a subpopulation of fin whales remained in the area throughout the summer for foraging. Analyses of stomach content data suggest that they feed primarily on euphausiids, but also on copepods, fish, and squid (Flinn *et al.* 2002). Like blue whales, fin whales communicate using low frequency sound (14-150 Hz).

2.2.2 Management

Over 1,000 fin whales were taken from the area during commercial whaling (Heise *et al.* 2003a). The fin whale population is currently estimated at 5,703 in the eastern North Pacific (Angliss and Outlaw 2005) based on line transect survey data. DFO's Cetacean Research Program is currently undertaking surveys for fin whales within PNCIMA.

2.2.3 Additional Information Sources

COSEWIC. 2005. COSEWIC Assessment and Update Status Report on the Fin Whale *Balaenoptera physalus* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 37p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

Gregr, E., J. Calambokidis, L. Convey, J. Ford, I. Perry, L. Spaven, M. Zacharias. 2005. Draft Recovery Strategy for Blue Whales (*Balaenoptera musculus*), Fin Whales (*B. physalus*) and Sei Whales (*B. borealis*) in Pacific Canadian Waters. Fisheries and Oceans Canada. Nanaimo, BC.

2.3 Sei Whale (*Balaenoptera borealis*)

2.3.1 Basic Biology and Habitat

Length: up to 18.6 m Lifespan: >50 yrs

Sei whales are considered a pelagic species and may have been more abundant than fin whales prior to commercial whaling (Ohsumi and Wada 1974). They were considered abundant off the continental slope of the west coast of Vancouver Island (Pike and MacAskie 1969). However, they were very heavily harvested during the final years of commercial whaling and they are now rarely seen (Heise *et al.* 2003b). Sei whales were harvested from May-August during their northbound migration to feeding areas, and in September when they returned south. Chapter 2 Map 2.19 reflects presumed habitat preferences based on historical whaling records. Sei whales taken from the area fed primarily on copepods, but also ate euphausiids, squid, and small fish (Nichol and Heise 1992; Flinn *et al.* 2002). Like other baleen whales, sei whales communicate using low frequency sound (1500-3500 Hz).

2.3.2 Management and Status

During the period of commercial whaling in British Columbia (BC), approximately 400 sei whales were taken within the slope area between Haida Gwaii and northwestern Vancouver Island (Heise *et al.* 2003b). Many other whales were taken in deep water off the west coast of Vancouver Island. DFO's Cetacean Research Program is currently undertaking surveys for sei whales within PNCIMA.

In 2005, the entire eastern North Pacific population estimate was only 35 sei whales (Carretta *et al.* 2005). It is possible that at present sei whale populations are not recovering because of the population level consequences of illegal harvesting by Russian, Japanese, and Korean whalers (Yablokov 1994; Baker *et al.* 2000). There is also growing concern that they may be negatively affected by increasing levels of underwater anthropogenic noise that may be interfering with their ability to use sound to communicate, navigate, and detect prey.

2.3.3 *Additional Information Sources*

COSEWIC. 2003. COSEWIC Assessment and Status Reports on the Sei Whale *Balaenoptera borealis* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 27p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

Gregr, E., J. Calambokidis, L. Convey, J. Ford, I. Perry, L. Spaven, M. Zacharias. 2005. Draft Recovery Strategy for Blue Whales (*Balaenoptera musculus*), Fin Whales (*B. physalus*) and Sei Whales (*B. borealis*) in Pacific Canadian Waters. Fisheries and Oceans Canada. Nanaimo, BC.

2.4 Humpback Whale (*Megaptera novaeangliae*)

2.4.1 *Basic Biology and Habitat*

Length: up to 17 m   Lifespan: >40 yrs

Humpback whales are frequently seen within PNCIMA and as a result are one of the better known species of cetaceans in the area. These whales can be individually identified based on distinct markings on the underside of their tail fluke. Over 1,500 have been identified to date within BC waters (J. Ford, unpublished data). Like other species of baleen whales, humpback whales migrate from low-latitude breeding areas in winter to high-latitude foraging areas in summer and fall. Humpbacks can be found year-round within PNCIMA, but it is not known whether these are non-migratory animals (J. Ford, unpublished data). Humpback whales feeding in BC may return to one of the three breeding areas in the North Pacific: Hawaii, Mexico, or Japan (Darling *et al.* 1996; Calambokidis *et al.* 2001).

Humpback whales communicate using low- to mid-frequency sounds (25-8,000 Hz). While in feeding areas, humpback whales are relatively quiet, but in breeding areas, male humpback whales 'sing'. All males within a breeding population sing the same song, although the song changes over time. These singing groups provide evidence of the existence of distinct cultural groups within humpback whale populations.

Both the historical whaling records and recent sighting data suggest that humpback whales make extensive use of much of PNCIMA, particularly Dixon Entrance and nearshore areas of the central coast and Haida Gwaii (Chapter 2 Map 2.15). Gregr and Trites (2001) suggest that sheltered bays and straits are also important habitat for humpback whales. In British Columbia, humpback whales feed primarily on euphausiids, but also take copepods and small fish such as herring (Nichol and Heise 1992).

2.4.2 Management

As many as 15,000-20,000 humpback whales may have inhabited the North Pacific prior to commercial whaling (Rice 1978), and over 1,300 were taken from within PNCIMA (Nichol and Heise 1992). By the time commercial whaling ended, there were only approximately 1,000 animals remaining in the North Pacific. Since protection, their numbers are recovering, and there are an estimated 6,500 animals in the eastern North Pacific (Angliss and Outlaw 2005; Carretta *et al.* 2005). Recognizing and ensuring the protection of culturally distinct 'groups' of humpback whales through management plans may facilitate their recovery. DFO's Cetacean Research Program is currently undertaking surveys for humpback whales within PNCIMA.

2.4.3 Additional Sources of Information

COSEWIC. 2003. COSEWIC Assessment and Update Status Report on the Humpback Whale *Magaptera novaengliae* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 25p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

2.5 Gray Whale (*Eschrichtius robustus*)

2.5.1 Basic Biology and Habitat

Length: 15 m Lifespan: >50 yrs

The Pacific gray whale population has generally recovered from the effects of exploitation, and currently numbers approximately 19,000 animals (Carretta *et al.* 2005). Gray whales are frequently seen within PNCIMA during their 15,000-20,000 km round trip migration from breeding areas in lagoons in Baja California, Mexico to foraging areas in the Bering Sea. The northward migration in BC begins in February, peaks in April and is over by June (Heise *et al.* 2003b). In late December to early January, sightings of southbound gray whales peak as they return to calving lagoons in Mexico, and most travel without stopping (Pike and MacAskie 1969).

During the northbound migration, approximately 1% of the population stops to forage en route, and feeding aggregations of gray whales are known to remain throughout the summer in a number of areas including the north and west coast of Vancouver Island, the central coast area around Cape Caution, and Skidegate Inlet (Calambokidis *et al.* 2002; Heise *et al.* 2003a; see Chapter 2 Map 2.14). Effort has been made by several organizations to individually photo-identify members of these 'resident' aggregations (Calambokidis *et al.* 2002). Genetic analysis has revealed that these whales are not genetically distinct from the larger population of gray whales that migrate through the area (Steeves *et al.* 2001).

Gray whales are generally benthic feeders that sieve small prey out of sediments or off vegetation, but they also feed in the water column and at the surface (Darling *et al.* 1998). Off the west coast of Vancouver Island, gray whales are known to prey on Pacific herring eggs and larvae, crab larvae, mysids, amphipods, and ghost shrimp (Darling *et al.* 1998; Dunham and Duffus 2001). Gray whales communicate in both breeding and foraging areas using low- to mid-frequency sound (35-2,000 Hz), although their use of sound is not as well understood as in other species such as the humpback whale.

2.5.2 Management

Gray whales were nearly extinct by 1900 because of extensive whaling in their calving lagoons, and they received international protection from commercial harvesting in 1938. The population recovered to a high of over 26,000 animals in 1997/1998 (Carretta *et al.* 2005). However, in 1999 and 2000 there was an unusually high number of strandings of gray whales, and their population is now estimated to be around 19,000 (Carretta *et al.* 2005), a decline of more than 25%. The Makah (Nuu-chah-nulth) people of Washington State have attempted to resume their traditional hunt of gray whales, although none has been taken since 1999.

In the western North Pacific, a genetically-distinct population of gray whales is critically endangered, with only 100-250 animals remaining (Clapham *et al.* 1999). Despite international agreements protecting the species, this population is not recovering, possibly due to illegal harvesting (Baker *et al.* 2002).

2.5.3 Additional Sources of Information

COSEWIC. 2004. COSEWIC Assessment and Update Status Report on the Gray Whale (Eastern North Pacific Population) *Eschrichtius robustus* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 31p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

2.6 North Pacific Right Whale (*Eubalaena japonica*)

2.6.1 Basic Biology and Habitat

Length: 18 m Lifespan: Unknown but long-lived

North Pacific right whales were hunted to commercial extinction by the mid-1800's, and their population has not recovered so there is little information on the species' biology or habitat requirements. Most sightings in recent years have been in the Gulf of Alaska and the Bering Sea (Angliss and Outlaw 2005). Diet information from populations in other areas suggests that right whales feed selectively on copepods (COSEWIC 2004).

2.6.2 Management and Status

In Alaska, extensive research is ongoing by the US National Marine Mammal Laboratory using visual and acoustic surveys for right whales. In BC, DFO's Cetacean Research Program is currently undertaking surveys for right whales within PNCIMA.

In addition to the threats discussed for all large baleen whales, North Pacific right whales are vulnerable to the 'Allee effect' where populations become reduced because individual members are unable to locate mates for reproduction.

2.6.3 Additional Sources of Information

COSEWIC. 2004. COSEWIC Assessment and Update Status Report on the North Pacific Right Whale *Eubalaena japonica* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 22p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

North Pacific Right Whale Recovery Team. 2004. National Recovery Strategy for the North Pacific Right Whale (*Eubalaene japonica*) in Pacific Canadian Waters. Fisheries and Oceans Canada. Vancouver, BC. 48p.

2.7 Minke Whale (*Balaenoptera acutorostrata*)

2.7.1 Basic Biology and Habitat

Length: 9.2 m Lifespan: >40 yrs

The minke whale is the smallest baleen whale found in PNCIMA. They feed on small schooling fish and are most commonly found alone in nearshore areas. Studies around the San Juan Islands suggest that in summer and fall they show small-scale spatial segregation (Dorsey *et al.* 1990) which may facilitate them feeding on prey that is patchily distributed in the environment. Individually recognizable minke whales have been resighted in the same areas over several years.

2.7.2 Management

Minke whales were not targeted by whalers in British Columbia, and relatively little is known about them here. In the western Pacific there are at least 2 distinct populations of minke whales, one of which is protected. In the Antarctic and the western Pacific, minke whales are the target of scientific whaling, including the protected population in the western Pacific (Dalebout *et al.* 2002).

2.7.3 Additional Sources of Information

Nothing recent.

3.0 TOOTHED WHALES, DOLPHINS, AND PORPOISES

There are at least 15 species of odontocetes that are found within the waters of PNCIMA, although only sperm and killer whales, Pacific white-sided dolphins, and Dall's and harbour porpoises are seen reliably. Below is a brief summary of the biology, habitat, and other relevant information for these more commonly encountered species. The four populations of killer whales (*northern* and *southern* residents, *transients* and *offshores*), and the harbour porpoise are listed species under COSEWIC.

3.1 Sperm Whale (*Physeter macrocephalus*)

3.1.1 Basic Biology and Habitat

Length: to 18 m Lifespan: >60 yrs

Sperm whales were relatively abundant within PNCIMA prior to commercial whaling. Whalers generally found them within 100 km of shore, particularly the west coasts of Haida Gwaii and Vancouver Island, and the stretch of water between them (Nichol *et al.* 2002). Males tended to travel alone or in small groups in nearshore areas, whereas females and juveniles travelled in larger groups that remained further offshore (Pike and MacAskie 1969). Gregr and Trites (2001) suggest that calving may take place in offshore BC waters. Although sperm whales are now uncommon within PNCIMA, they continue to be found in the same areas they frequented prior to commercial whaling (see Map 7 in Heise *et al.* 2003b; also see Chapter 2 Map 2.20 of this report).

Stomach content analyses from whales landed at Coal Harbour found that in the spring, male and female sperm whales ate fish and squid, but later in the season males consumed more fish than females (Flinn *et al.* 2002), likely reflecting their nearshore distribution during the summer.

In other areas of the world, studies of sperm whales have revealed that they show complex social and acoustical behaviours (Whitehead 2003). They produce a wide variety of low frequency clicks in either regular patterns or in unique sequences called 'çodas' and there is good evidence that they have group-specific dialects. The basic element of their social organization is a long-term association of 10-12 females and their young, known as a 'unit'. Groups of units may associate temporarily, but all form part of larger acoustic 'clans' that may contain thousands of animals and range over a very large geographic area.

3.1.2 Management

Between 1905 and 1967 more than 5,000 were taken from the west coast of British Columbia (Pike and MacAskie 1969). There are no current population estimates for sperm whales in BC or Alaskan waters, but there are an estimated 585 animals off the coasts of Washington, Oregon, and California (Carretta *et al.* 2005).

Sperm whales are well known to interact with commercial fishing vessels, and in some areas this has created conflict or resulted in changes to fishing practices. In Alaska, sperm whales regularly take fish from longline gear, and in BC they consume offal discarded by boats fishing for black cod (J. Ford, unpublished data).

3.1.3 Additional Sources of Information

Nothing recent.

3.2 Killer Whale (*Orcinus orca*)

3.2.1 Basic Biology and Habitat

Length: to 9 m (males) Lifespan: males 50, females 80 yrs

There are 3 distinct ecotypes of killer whales that travel the waters of BC (Ford *et al.* 2000), *resident*, *transient*, and *offshore*.

Resident Killer Whales:

Two distinct populations of resident-type killer whales, the *northern* and *southern* residents, are known to travel within PNCIMA. These populations are acoustically, genetically, and culturally distinct. Although their winter distribution is not well understood, in spring through fall the *northern* residents spend the majority of their time in coastal waters from central Vancouver Island northwest to Dixon Entrance (Chapter 2 Map 2.16). In summer and fall *southern* residents have occasionally been seen as far north as Haida Gwaii, but in general their distribution is concentrated in areas south of PNCIMA. Johnstone Strait and southeastern portions of Queen Charlotte Strait and adjoining channels have been proposed as critical habitat for the northern residents during the summer and fall, when a portion of the population is reliably found in the area (KWRT 2007). Both the northern and southern residents feed on fish and rely heavily on chinook salmon (*Oncorhynchus tshawytscha)* and chum salmon (*O. keta*) in their diet during the summer and fall.

Killer whales are individually recognizable, and studies over the past 30 years have revealed that resident killer whale societies are extremely complex. Northern and southern residents are culturally very distinct from each other, and the two populations do not associate. Because there is no dispersal of whales from their natal group, it is possible to census each resident population with reasonable precision. In 2003 there were 85 whales in the southern resident population, and 205 whales in the northern resident population (KWRT 2007).

Transient Killer Whales:

Approximately 220 transient killer whales have been identified in the coastal waters of BC (Ford and Ellis 1999), and they can be found throughout PNCIMA. Unlike resident killer whales, the distribution of transient killer whales is unpredictable, likely because they feed on a variety of marine mammals, from large whales to harbour seals (Ford *et al.* 1998), which occupy a variety of habitats. They are also acoustically distinct, although their vocal repertoire is not as complex as that of resident killer whales. The social behaviour of transient killer whales is not well understood, but there does appear to be dispersal from the natal group.

Offshore Killer Whales:

Over 250 offshore killer whales have been photo-identified, but little is known of their diet, behaviour, or distribution. They appear to travel in large, acoustically active groups. There is evidence that they feed on fish (Heise *et al.* 2003a; Jones 2006), although they may take other prey as well. Encounters with offshore killer whales are relatively infrequent, but their name reflects the belief that they likely spend most of their time in offshore waters (Ford *et al.* 2000).

3.2.2 Management

The Cetacean Research Program (DFO Nanaimo) in conjunction with the Centre for Whale Research (Friday Harbour, San Juan Islands) undertakes photo-identification studies to monitor changes in killer whale populations. Although little is known of the status of offshore killer whales, residents and transients are at risk because of their inherently small size, low reproductive rate, and their vulnerability to a wide variety of anthropogenic threats. The SARA (*Species at Risk Act*) Recovery Strategy for resident killer whales is awaiting approval by the Minister, after which time an Action Plan will be developed. Northern and southern residents must be considered separate populations for conservation actions to be successful.

3.2.3 Additional Sources of Information

Killer Whale Recovery Team. 2007. DRAFT National Recovery Strategy for Northern and Southern Resident Killer Whales (*Orcinus orca*). Prepared for Public Consultations, Spring 2005, for Fisheries and Oceans Canada, on behalf of the Resident Killer Whale Recovery Team (KWRT). 70p.

3.3 Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)

3.3.1 Basic Biology and Habitat

Length: up to 2.5 m   Lifespan: >40 yrs

Pacific white-sided dolphins are generally found in large, gregarious, acoustically active groups throughout PNCIMA, in habitats ranging from inlets to offshore waters (Heise *et al.* 2003b). In nearshore waters they tend to be found in smaller groups, and offshore their numbers can exceed 1000 or more. In the coastal waters of BC, they feed primarily on herring, salmon, and other small schooling fish, as well as shrimp and squid. Further offshore they feed on mesopelagic fish and squid (Walker and Jones 1993).

3.3.2 Management

The high seas flying squid driftnet fishery resulted in a bycatch of 50,000-80,000 dolphins between 1978 and 1990, but ended in 1992 (Tanaka 1993). Population estimates for the North Pacific range widely, from 206,000-4,216,000 (mean 931,000, CV=0.90; Buckland *et al.* 1993). Because these dolphins are attracted to vessels they are difficult to reliably census from ship surveys.

3.3.3 Additional Sources of Information

Nothing recent.

3.4 Dall's Porpoise (*Phocoenoides dalli*)

3.4.1 Basic Biology and Habitat

Length: up to 2.4 m   Lifespan: 15 yrs

Dall's porpoises are widely distributed throughout PNCIMA. They are reported in all months of the year in both offshore and nearshore locations around Haida Gwaii, where they tend to be found in small groups (Heise *et al.* 2003b). Unlike the Pacific white-sided dolphin, and most other cetaceans, Dall's porpoises are relatively short lived, with a maximum lifespan of 15 years. They appear to reproduce annually after age 4, and the peak of calving occurs in early July (Ferrero and Walker 1999).

In other areas, Dall's porpoises are known to feed on small schooling fish and squid, but there is little diet information available for BC waters. Dall's porpoises are an important prey item for transient killer whales.

3.4.2 Management

Ship surveys must take into account the attraction that Dall's porpoises have towards boats. A correction factor of 0.2 to the population estimate has been calculated to compensate for this behaviour (Turnock and Quinn 1991).

3.4.3 Additional Sources of Information

Nothing recent.

3.5 Harbour Porpoise (*Phocoena phocoena*)

3.5.1 Basic Biology and Habitat

Length: up to 2 m   Lifespan: 10-12 yrs

Harbour porpoises are found throughout PNCIMA in water less than 200 m deep. Unlike Dall's porpoises, they are shy and usually avoid boats. They are often found alone or in very small groups (Heise *et al.* 2003b) and feed on small schooling fish (<40 cm). Harbour porpoises are an important prey item for transient killer whales. Unlike most of the cetacean species discussed here, harbour porpoises are relatively short lived. They reproduce annually after age 3-4, and calving takes place from May through September.

3.5.2 Management

Genetic and contaminant analyses has revealed that harbour porpoises may be very restricted in their movements (Calambokidis and Barlow 1991; Chivers *et al.* 2002). This may have important consequences for the development of recovery strategies for the species. They are also vulnerable to coastal fisheries. They carry high contaminant levels, which may reflect their nearshore distribution (Ikonomou *et al.* 2002).

3.5.3 Additional Sources of Information

COSEWIC. 2003. COSEWIC Assessment and Update Status Report on the Harbour Porpoise *Phocoena phocoena* (Pacific Ocean Population) in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 22p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

4.0 PINNIPEDS

There are 5 species of pinnipeds found within PNCIMA. These include Steller and California sea lions, northern fur seals, northern elephant seals, and Pacific harbour seals. Only Steller sea lions and harbour seals occur year round and breed within PNCIMA. All other species are seasonal migrants, although individuals may remain year round. Steller sea lions are currently the only listed pinniped species under COSEWIC, but the status of northern fur seals is under review.

4.1 Steller Sea Lion (*Eumetopias jubatus*)

4.1.1 Basic Biology and Habitat

Size: Males 400-800 (max 1,100) kg	Females 200-350 kg
Lifespan: Males 15 yrs	Females 25 yrs

Steller sea lions are generally found within 60 km of land in summer and 200 km in winter and are distributed over the continental shelf and along the shelf break when they are not hauled out on land (Figure J.1). They have an eclectic diet and consume over 50 species of fish and invertebrates, but feed primarily on small schooling fish and squid. There are two genetically distinct populations of Steller sea lions recognized in the North Pacific, the *eastern* and *western* populations. Breeding occurs from May to August, and the eastern population breeds on three rookeries within PNCIMA (identified in red on Chapter 2 Map 2.21) and on a 4th rookery on Forrester Island, Alaska, just north of the area. Females can reproduce each year, but young are often nursed into their second and sometimes even third year, and there is high rate of reproductive failure. Only males who hold territories on the breeding rookeries mate.

Steller sea lions are non-migratory, but disperse widely from breeding rookeries to winter haulouts spread throughout the area, including protected waters. Year-round haulouts, which are generally situated in more exposed locations, are used by breeding animals outside the breeding season, and by non-breeding animals throughout the year.

4.1.2 Management and Status

Steller sea lions were subject to culls prior to their protection in 1970, because they were perceived to compete with commercial fishermen for their prey. Since protection, the eastern population has been recovering. DFO has been conducting province-wide surveys during the breeding season every 4-5 years since the early 1970s, and since the mid-1980s these have been coordinated throughout the range with other agencies.

The western Alaska population of Steller sea lions has declined dramatically since the mid-1970s, and is considered endangered under the US Endangered Species Act. Reasons for the decline in the west remain unknown. In contrast, the eastern population in BC and neighbouring waters has been increasing, but has been designated Special Concern by COSEWIC mainly due to the limited number of breeding sites in Canadian waters.

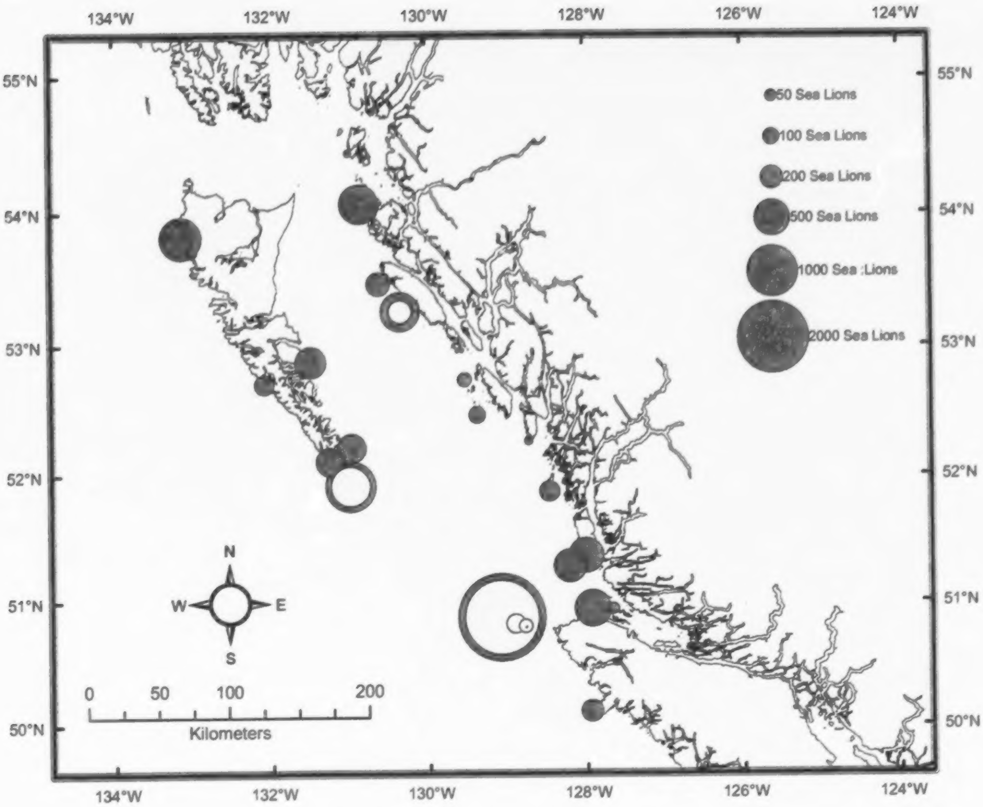

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Figure J.1 Distribution of sea lion haulout sites (solid red circles) and breeding rookeries (red circles with yellow centers) within PNCIMA. Red circles are drawn proportional to the number of non-pups observed at each site and the inner yellow circles proportional to the number of pups born on rookeries based on a coast-wide survey conducted in 2002. Preliminary visual counts from a coast-wide survey flown in 2006 indicate a similar distribution.

4.1.3 Additional Sources of Information

Olesiuk, P.F. 2003. Recent Trends in the Abundance of Steller Sea Lions (*Eumetopias jubatus*) in British Columbia. NMMRC Working Paper No. 2003-10.

COSEWIC. 2003. COSEWIC Assessment and Update Status Report on the Steller Sea Lion *Eumetopias jubatus* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 47p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

4.2 Northern Fur Seal (*Callorhinus ursinus*)

4.2.1 Basic Biology and Habitat

Size:	Males 140-280 kg	Females 30-50 kg
Lifespan:	Males: 12-18 yrs	Females: 20-25 yrs

Most fur seals in the NE Pacific breed on the Pribilof Islands in the Bering Sea in summer, and are widely dispersed throughout the North Pacific at other times, generally within 20-150 km of shore (Figure J.2). Perhaps half the population may pass along the BC coast during its annual migration, the majority of which travel along the west coast of Vancouver Island and Haida Gwaii (Bigg 1990; Heise *et al.* 2003a). However, from January through April, Hecate Strait supports a large overwintering population which feeds primarily on fish and squid. They tend to aggregate in certain areas in Hecate Strait (see Chapter 2 Map 2.22), likely to feed on herring (Heise *et al.* 2003a).

4.2.2 Management

Periods of commercial harvesting for fur seal pelts dates back to the mid 1700s, and Victoria was an important sealing port during the late 1800s and early 1900s. During this time the population went through various declines, as several million animals were taken. There has been no commercial harvest for fur seals since the mid 1960s, but between 1958 and 1974 over 18,000 animals were killed for scientific research purposes. In 1974 the population numbered 1.25 million animals, but in recent years it has declined to 888,000 (Angliss and Outlaw 2005), and fur seals are now considered 'depleted' under the Marine Mammal Protection Act in the United States.

4.2.3 Additional Sources of Information

COSEWIC. 2004. Interim COSEWIC Assessment and Update Status Report on the Northern Fur Seal, *Callorhinus ursinus,* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 32p. (Draft – 28 September 2004).

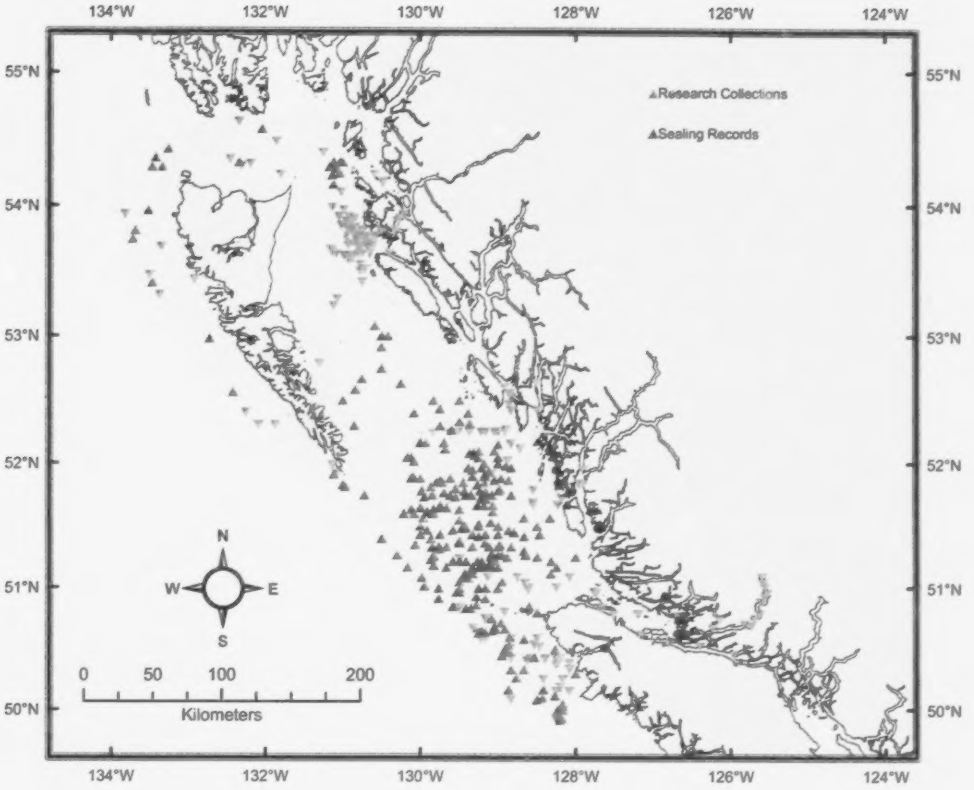
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Figure J.2 Pelagic distribution of northern fur seals within PNCIMA based on the locations of North Pacific Fur Seal Commission research specimen collections and historic records of fur seal harvests from sealing logbooks.

4.3 Pacific Harbour Seal (*Phoca vitulina richardsi*)

4.3.1 Basic Biology and Habitat

Size: 65-90 kg Lifespan: Males 20 yrs; Females 30 yrs

Harbour seals are widely distributed and breed throughout PNCIMA, and about 600 known haulout sites have been documented within the area (~80% of which has been surveyed; Figure J.3). Harbour seals are non-migratory and show a degree of fidelity to these traditional sites, although they undertake local movements to take advantage of seasonally and locally abundant prey (*e.g.*, to river mouths and estuaries in the fall to feed on spawning salmon). They are opportunistic predators and consume a wide variety of fish, cephalopods, and other invertebrates. Females give birth to a single pup on haulout sites. Pups are precocious at birth and can enter the water within a few hours.

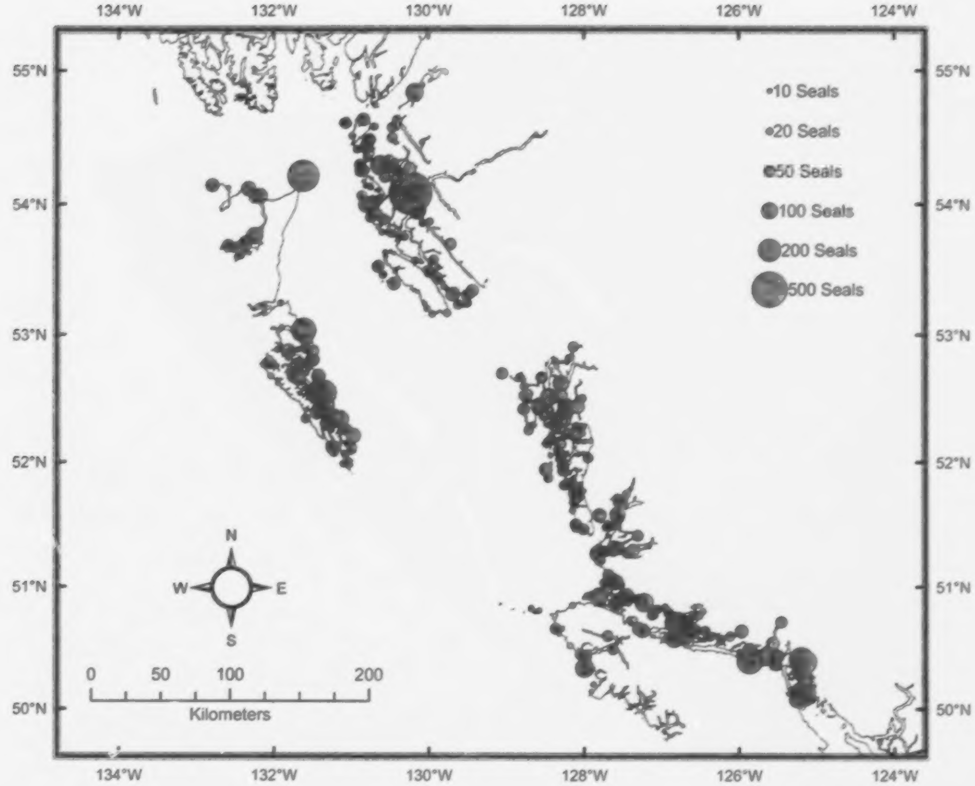
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Figure J.3 Distribution of harbour seal haulout sites within PNCIMA. Red circles are drawn proportional to the maximum number of seals observed at each site. Sections of the coastline in grey denote areas where baseline surveys have not been conducted.

4.3.2 Management

Prior to being protected in 1970, there was an intense commercial harvest for their pelts during the 1960s, and they were also the subject of a federal bounty program since the early 1900s. Populations were depleted to about 10% of historic abundance by the time they were protected in 1970, but increased dramatically during the 1970s, 1980s, and early 1990s, and have now probably attained historic levels.

4.3.3 Additional Sources of Information

Olesiuk, P. F. 1999. An Assessment of the Status of Harbour Seals (*Phoca vitulina*) in British Columbia. Canadian Stock Assessment Secretariat Research Document. 99/33. Fisheries and Oceans Canada.

5.0 OTHER MARINE ANIMALS OF INTEREST

5.1 Sea Otter (*Enhydra lutris*)

5.1.1 Basic Biology and Habitat

Size: 20-30 kg Lifespan: Males 10-15 yrs, Females 15-20 yrs

Sea otters breed year round, although pupping peaks during March and April in British Columbia (Watson 1993). By 1929, sea otters were hunted to extinction in British Columbia, but between 1969 and 1972, 89 sea otters were re-introduced to the west coast of Vancouver Island from the Aleutian Islands and Prince William Sound, Alaska, in an effort to re-establish the species in Canada. Between 1977 and 1995 their population grew at 18.6% per year to at least 1,500 animals by 1995 (Watson *et al.* 1997). Since then, growth has continued to be positive but has slowed in recent years along Vancouver Island, such that the average rate between 1977 and 2004 was 15.6% per year (Nichol *et al.* 2005). A total of 3,180 sea otters were counted in recent complete surveys in 2001, of which 2,673 sea otters were counted along the west coast of Vancouver Island and 507 on the central mainland coast. Similar counts were obtained in 2002-2004 (Nichol *et al.* 2005). Sea otters were first reported on the central mainland coast in 1989 (BC Parks 1995). The sea otter population now ranges along the west coast of Vancouver Island from Clayoquot Sound to Cape Scott and eastward to Hope Island in Queen Charlotte Strait. On the central mainland coast, sea otters range from the Goose Group northward to the edge of Milbanke Sound (Nichol *et al.* 2005; Chapter 2 Map 2.23).

Sea otters are a nearshore species and typically occur within 1-2 km from shore and in waters less than 40 m deep (Reidman and Estes 1990). Sea otters feed on benthic invertebrates such as sea urchins, bivalves, snails, chitons, crabs, and sea stars. Most foraging occurs in waters of 30 m or less, although sea otters are capable of diving to 100 m (Reidman and Estes 1990; Bodkin *et al.* 2004). Kelp beds, an important component of sea otter habitat, are used as resting areas and foraging areas. Soft-bottom communities that support clam species are also important foraging habitat for sea otters.

Sea otters do not have a blubber layer to protect them from the cold. Instead they rely on a very rapid metabolism and extremely dense fur for insulation. To fuel their high metabolism, sea otters consume approximately 23-33% of their body weight in prey per day (Reidman and Estes 1990).

5.1.2 Management and Status

Under the *Species at Risk Act*, sea otters are listed as Threatened, and are protected from being killed, harmed, captured, or harassed. DFO continues population assessment research on the central mainland coast and on Vancouver Island. The Checleset Bay Ecological Reserve is an area just outside of PNCIMA where sea otter habitat is specifically protected, and commercial harvesting for many of the prey species of sea otters, such as geoducks, urchins, and sea cucumbers, is prohibited.

The sea otter population in British Columbia is relatively small with a limited geographic distribution. Given the species' inherent vulnerability to oil, these factors place the sea otter at risk.

5.1.3 Additional Sources of Information

Sea Otter Recovery Team. 2003. National Recovery Strategy for the Sea Otter (*Enhydra lutris*) in Canada. Fisheries and Oceans Canada. Ottawa, Ontario. 60p. Accessed February 2006 at http://www.pac.dfo-mpo.gc.ca/comm/pages/consultations/sea-otters/default_e.htm.

Sea Otter Recovery Team. 2004. National Recovery Plan for the Sea Otter (*Enhydra lutris*) in Canada 2004-2009. Fisheries and Oceans Canada. Ottawa, Ontario. 35p. Accessed February 2006 at http://www.pac.dfo-mpo.gc.ca/comm/pages/consultations/sea-otters/default_e.htm.

5.2 Leatherback Turtle (*Dermochelys coriacea*)

5.2.1 Basic Biology and Habitat

Length: up to 2 m Lifespan: unknown but >15 yrs

Leatherback turtles are a large marine reptile, but we have included them here because they a) are considered Endangered under SARA, b) are a long-lived, low fecundity species that occupies a large geographic range, c) occupy an ecological niche similar to large baleen whales that are low trophic level foragers that enter PNCIMA seasonally, and d) are vulnerable to many of the threats facing marine mammals. Leatherbacks feed primarily on jellyfish and soft-bodied invertebrates. Adult leatherback turtles enter BC coastal waters between June and November, likely to exploit seasonal abundances of jellyfish (Spaven and Ford 2006; Chapter 2 Map 18). Juveniles appear to remain in tropical waters, possibly because they are physiologically restricted from entering colder water.

The timing and location of mating is not known, but in the Pacific, nesting occurs on beaches in Mexico, Costa Rica, and Irian Jaya. During incubation and emergence, leatherback turtles are vulnerable to predation and disturbance.

5.2.2 Management and Status

Leatherback turtles travel over large geographic areas and through the jurisdiction of many different countries, so successful management practices will require multilateral collaboration. Although conservation measures have focused on protecting eggs on nesting beaches, there is growing recognition of the importance of protecting adult and sub-adult turtles from fishing interactions. The effects of interactions with fishing gear are an important concern for many of the SARA-listed species.

In 1980 there were an estimated 115,000 leatherback turtles worldwide, but in 1995 that number had declined to 34,500 and they now may be facing imminent extinction in the Pacific.

5.2.3 Additional Sources of Information

COSEWIC. 2001. COSEWIC Assessment and Update Status Report on the Leatherback Turtle *Dermochelys coriacea* in Canada. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Ottawa, Ontario. 25p. Accessed February 2006 at www.sararegistry.gc.ca/status/status_e.cfm.

Fisheries & Oceans Canada (DFO) and the Pacific Leatherback Turtle Recovery Team. 2004. National Recovery Strategy for the Leatherback Turtle (*Dermochelys coriacea*) in Pacific Canadian Waters. Vancouver, BC.

Pacific Leatherback Turtle Recovery Team (PLTRT). 2003. Draft National Recovery Action Plan for the Leatherback Turtle in Pacific Canadian Waters. Fisheries and Oceans Canada. Ottawa, Ontario. 18p.

6.0 THREATS TO MARINE MAMMALS AND SEA TURTLES

There are both chronic and acute threats to marine mammal populations within PNCIMA. In addition, some species, such as fin whales and leatherback turtles, travel over large geographic distances. They are thus vulnerable to threats, such as illegal harvesting, that occur outside PNCIMA. The majority of marine mammals discussed here are long-lived and have low reproductive rates, and populations are generally slow to recover if depleted. Below is a brief summary of some of the anthropogenic threats to marine mammals.

- Historical Whaling and Sealing / Illegal Harvest - Although commercial whaling and sealing has now ended in BC waters, some populations, particularly cetaceans, have failed to recover, due in part to their intrinsically slow rates of increase. There is also evidence that whales continue to be taken illegally by Japanese and Korean whalers (Baker *et al.* 2000).
- Ship Strikes - Ships, particularly those capable of travelling over 14 knots, can be a problem for cetaceans (Laist *et al.* 2001). North Pacific right, blue, fin, sei, and killer whales (all SARA-listed species) are known to be vulnerable to ship or propellor strikes.
- Chronic Anthropogenic Noise - Many marine mammals use sound much in the way terrestrial animals use vision: to detect prey and predators, to communicate, and to acquire information about their environment. Ambient underwater noise has increased dramatically in recent years, and may interfere with many of these processes (National Research Council 2003), particularly for large baleen whales, and may be a factor slowing recovery of some populations.

- Acute Anthropogenic Noise - There is growing concern that marine mammals may be vulnerable to acute sources of sound, such as construction blasting, seismic surveys, and high energy military sonars. These sounds can cause physiological damage, temporary and / or permanent changes in hearing thresholds, the production of stress hormones, and tissue damage.

- Reduced Prey Availability - While it is difficult to assess whether some species may be prey-limited when the diets of many species of marine mammals are not well known, the issue of bottom-up processes is receiving growing consideration. Prey abundance can be affected by natural processes, such as regime shifts and global warming, and some commercially harvested species have been depleted. This issue has received a great deal of attention in the Bering Sea and Gulf of Alaska, where there is some evidence that populations of pinnipeds have experienced significant declines in recent years, and nutritional stress may have played a role.

- Entanglement - Small cetacean populations in many areas of the world may be threatened by gear entanglement in commercial fisheries. In BC, harbour and Dall's porpoises may be especially vulnerable. Entanglement in debris has been implicated in fur seal population declines, and its not uncommon to see sea lions with packing bands or net fragments around their necks.

- Biological and Chemical Contamination - Marine mammals, particularly higher trophic level predators such as resident and transient killer whales, are known to be vulnerable to accumulating chemical contaminants such as PCBs (polychlorinated biphenyls) and PBDEs (polybrominated diphenylethers), which can result in immunosuppression, reproductive impairment, and endocrine disruption. They are also vulnerable to biological pollutants such as *Morbillivirus*, which can spread extremely quickly in the marine environment because there are few barriers to dispersal.

- Pollution - In addition to the threats posed by environmental contaminants, ingestion of floating materials by skim feeders such as right whales, sei whales, and leatherback turtles may be a threat to some species. Sea lions and fur seals can also become entangled in materials such as plastic rings, resulting in slow strangulation as the animals grow.

- Oil Spills - Sea otters are particularly vulnerable to oil spills. In BC, the population is still relatively small and limited in distribution, placing the population at risk in the event of an oil spill. Oil destroys the insulating quality of their fur, resulting in hypothermia and death. Several behavioural characteristics place sea otters at particular risk from oil. Sea otters aggregate in sex-segregated resting groups that can number up to 200 animals and thus large portions of the population can be affected at once. Sea otters tend to form these resting aggregations near kelp beds, areas that will accumulate and retain oil. Finally sea otters may be chronically contaminated through consumption of contaminated benthic prey long after a spill has occurred.

- Disturbance - Boat traffic, marine mammal watching, and other human activities may physically disturb animals, reducing their ability to undertake daily activities. Leatherback turtles are also vulnerable to human activities on their nesting beaches.
- Climate Change - It is difficult to predict the effects of climate change on marine mammals because such effects are likely to be widespread across the ecosystem. Most likely marine mammals will be affected by changes in the abundance and distribution of their food supply.
- Low Population Size - It may be difficult for some species that range over large geographic areas and that have been reduced to very low numbers, such as sei whales and North Pacific right whales, to physically locate mates for reproduction.

7.0 ECOSYSTEM LINKAGES

Over 25 species of marine mammals and reptiles can be found within PNCIMA, of which 13 are listed under SARA (Table J.0). The following paragraph pertains directly to SARA-listed species. Blue, fin, and sei whales tend to be found along the western boundary of PNCIMA, along the continental slope where the water is more than 200 m deep (Chapter 2 Maps 2.17, 2.18, and 2.19), and this is where leatherback turtles are found most commonly (Chapter 2 Map 2.24). This area of high productivity has been identified as an Important Area (IA) in preliminary discussions on Ecologically and Biologically Significant Areas (EBSAs) due to its physical oceanography. Dixon Entrance is an IA for blue, humpback, and resident killer whales (Chapter 2 Maps 2.17, 2.15, and 2.16, respectively). The east coast of Haida Gwaii is an IA for gray whales (Chapter 2 Map 2.14) and leatherback turtles (Chapter 2 Map 2.24), and also for harbour porpoises because they are generally found in water less than 100 m deep. The mainland coast is an IA for resident killer whales (Chapter 2 Map 2.16) and portions of this area are important for humpback, gray, and fin whales, and for sea otters (Chapter 2 Maps 2.15, 2.14, 2.18, and 2.23). As sea otter numbers continue to increase, other shallow water areas within PNCIMA may become important habitat. Much of the entire PNCIMA is an IA for Steller sea lions (Chapter 2 Map 2.21), in part because it contains the 3 main breeding rookeries on the coast, and because sea lions travel large distances when foraging.

Non-SARA-listed species that are relatively abundant and that are found throughout PNCIMA include harbour seals, Pacific white-sided dolphins, and Dall's porpoises. Sperm whales are more restricted in their use of the area, and are generally found along the continental slope in deeper water (Chapter 2 Map 2.20). It is in this area that they are known to remove fish from longline gear and consume offal from commercial fishing vessels.

As a group, marine mammals and leatherback turtles feed on a diversity of prey species. Within the group, some species, such as the baleen whales, are restricted to zooplankton and small schooling fish. Dolphins, porpoises, and pinnipeds consume prey ranging from zooplankton to large fish. Killer whales are high trophic level foragers, feeding on prey ranging from fish to other marine mammals.

8.0 INFORMATION GAPS, UNCERTAINTIES, AND LIMITATIONS

Few of the over 25 species of marine mammals and leatherback turtle that are found within PNCIMA have been the subject of focused studies, and much of what is known about their life history, distribution, and abundance has been collected opportunistically or has been inferred from research in other areas. The exceptions to this are the reasonable number of studies that have been done on Steller sea lions, harbour seals, and killer whales, although many questions remain, even for these species. The following is a general summary of the gaps and uncertainties in our knowledge of the marine mammals of PNCIMA.

- Habitat use, particularly for more pelagic species, including migration routes and timing of migration, feeding areas, seasonality of use.
- Definition of and identification of critical habitat, particularly for SARA-listed species.
- Population sizes and trends for most species of cetaceans, as well as leatherback turtles.
- Breeding areas for cetaceans and leatherback turtles.
- Historical abundance, in order to better understand what populations were in the area prior to exploitation.
- Effects of environmental contaminants on marine mammals, their habitat, and their prey.
- Effects of environmental catastrophes.
- Effects of climate change and regime shifts.
- For species such as North Pacific right whales and leatherback turtles, basic biology and ecology.
- Diet and energetic requirements.
- Role of apex predators in ecosystem.
- Long and short term effects of physical disturbance.
- Long and short term effects of acoustic disturbance.
- Population level consequences of low population size.
- Consequences of changes in prey populations.

9.0 GLOSSARY

Allee effect – Where populations become reduced because individual members are unable to locate mates for reproduction.

Cultural groups – A body of traditions, social conventions, and other knowledge that is transferred across and between generations through learning. Non-human examples of culture can be found in species such as primates, sperm whales, and killer whales.

Mesopelagic – Pertaining to the region of the open ocean at depth from 200-1000 m.

Offal – Discarded viscera, heads, and other animal parts considered unfit for human comsumption.

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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX K: MARINE BIRDS

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1.0 INTRODUCTION

This chapter provides a general overview of birds that are closely associated with marine habitats in the Pacific North Coast Integrated Management Area (PNCIMA; Figure K.0). In this account, the term 'marine birds' refers to those birds which use marine habitats during at least part of their life cycle. For the purposes of this overview, birds that have similar habits or which use similar habitats have been grouped together and are listed in decreasing order of their use of, or dependence on, the marine environment:

- **Seabirds:** This group is restricted to those birds which spend most of their time on open water. These birds are often referred to as 'pelagic seabirds' and include the tubenoses (albatrosses[1], fulmars, shearwaters, and storm-petrels); cormorants; jaegers, skuas, gulls, and terns; alcids (murres, guillemots, murrelets, auklets, and puffins); and phalaropes (although the latter may also be categorized as shorebirds).
- **Waterfowl and Allies:** This group includes species that commonly breed inland near fresh water but either migrate along the coast during spring and fall or use marine habitats for moulting and wintering. Loons, grebes, swans, geese, ducks, and cranes are included in this group due to similarities in their habitat use. Ducks are sometimes further divided into dabbling ducks, which tend to stay nearshore and in estuaries, and sea ducks or diving ducks, whose habitats include more open marine waters.
- **Shorebirds:** Shorebirds generally breed inland (mostly in the Arctic) but forage along southern sea coasts during winter and spring and fall migration. These birds include plovers, oystercatchers, and sandpipers. Herons are included in this group because they also use nearshore habitats for foraging.
- **Birds of Prey and Scavengers:** In addition to these marine birds, birds of prey (Ospreys, Bald Eagles, and Peregrine Falcons) and scavengers (Northwestern Crows and Common Ravens) are mentioned in this review because they often live near the coast and make extensive use of resources from the marine environment. However, they are not dependent on the marine ecosystem as are seabirds, waterfowl, and shorebirds. As a result, these groups are not discussed in detail in this appendix, but their association with other marine birds is mentioned.
- Most species of seabird, waterfowl, shorebird, raptor, and scavenger are considered "migratory birds" and as such, are protected under the *Migratory Bird Convention Act*, and managed by Canadian Wildlife Service (CWS) of Environment Canada.

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[1] Full list of species provided in Figure K.1

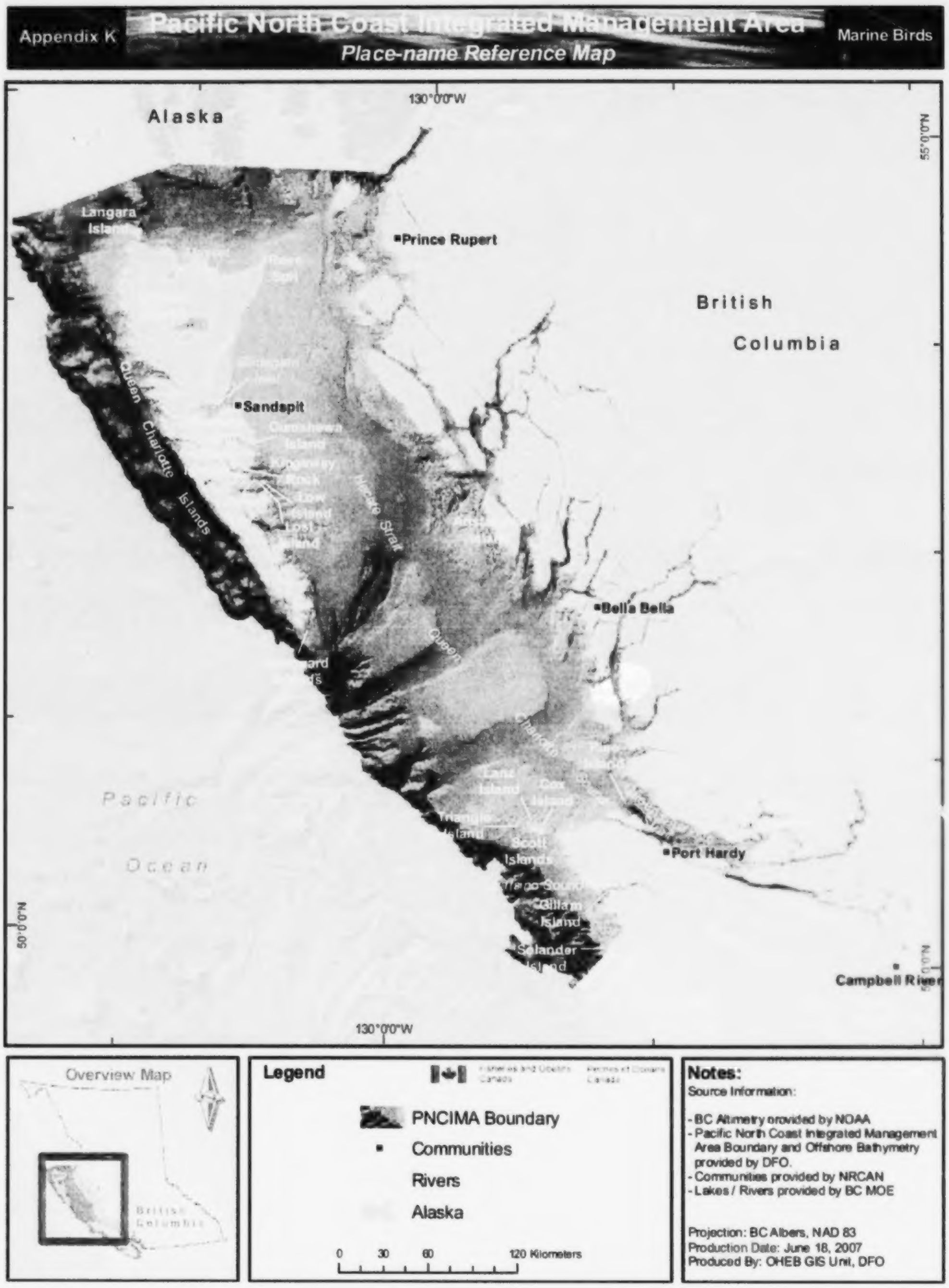
Appendix K
Pacific North Coast Integrated Management Area
Place-name Reference Map
Marine Birds
130°0'0"W
Alaska
55°0'0"N
Langara Island
Prince Rupert
British Columbia
Queen Charlotte Islands
Sandspit
Cumshewa Island
Kingsway Rock
Low Island
Lost Island
Hecate Strait
Bella Bella
Queen Charlotte Sound
Lanz Island
Cox Island
Triangle Island
Scott Islands
Port Hardy
Gillam Island
Solander Island
Campbell River
Pacific Ocean
50°0'0"N
Overview Map
British Columbia
Legend
PNCIMA Boundary
Communities
Rivers
Alaska
0 30 60 120 Kilometers
Notes:
Source Information:
- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE
Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure K.0 PNCIMA region showing locations and features of BC waters.

2.0 SIGNIFICANCE OF MARINE BIRD POPULATIONS

2.1 British Columbia

- British Columbia (BC) has globally significant populations of some species of colonially breeding seabirds. Based on Rodway's (1991) data, it was determined that 80%, 74%, and 56% of the global breeding population of Cassin's Auklets, Ancient Murrelets, and Rhinoceros Auklets, respectively, breed along the BC coast.
- As of 1991, over 5.6 million colonial seabirds were estimated to be nesting at 503 known sites (mostly small islands) along the BC coast. Five species accounted for most of this breeding population: Cassin's Auklet (48% of the total population), Fork-tailed Storm-petrel and Leach's Storm-petrel (27%), Rhinoceros Auklet (13%), and Ancient Murrelet (10%; Rodway 1991).
- In a recent assessment of non-breeding seabird populations of the North Pacific Ocean, an estimated 550,000 non-breeding seabirds use the marine environment off the BC coast from June through August (PICES 2004). During spring and fall, the number of birds that migrate through the area is estimated to be an order of magnitude greater (Hipfner *et al.* 2002).
- Almost the entire world's population of Brant migrates along the BC coast each spring (Booth 2000).
- The Western Sandpiper is the most abundant shorebird in BC; most of the world's population migrates along the BC coast in spring and autumn. Flocks can reach or exceed 100,000 birds (Campbell *et al.* 1990b).

2.2 PNCIMA

- Approximately 54% (108 of 201) of the marine bird species recorded in BC are known or believed to use habitats in the PNCIMA region during part or all of their life cycle (Figure K.1). This includes 71% (43 of 60 species) of seabirds, 65% (39 of 57) of waterfowl, and 40% (23 of 59) of shorebirds found in the province.
- PNCIMA includes most of the major seabird colonies that occur in BC. These include colonies in the Scott Islands, Queen Charlotte Islands, Queen Charlotte Sound, Quatsino Sound, and near Brooks Peninsula. As a result, 95% of all of BC's breeding seabirds occur in PNCIMA. This includes:
    - all of the known nesting areas within BC (and Canada) of Ancient Murrelets (most of which occur on the Queen Charlotte Islands);
    - all of BC's population of Common Murres (<7000 birds) at only two sites: Triangle Island and Kerouard Islands (Hipfner 2005);

    - more than 99% of the BC's nesting Cassin's Auklets, Rhinoceros Auklets, Fork-tailed Storm-petrels, and Horned and Tufted Puffins;
    - 97% of the province's Leach's Storm-petrels and 85% of its nesting population of Pigeon Guillemots (Rodway 1991).
- Thirty-three marine bird species or subspecies of conservation concern occur in PNCIMA (see section 3.5). These include 21 species of seabird, 6 waterfowl, 4 shorebird, and 2 falcons.
- PNCIMA contains important wintering and staging areas for several species of waterfowl and shorebird (Badzinski *et al.* 2005).

Order	PNCIMA Relevant Families	# BC Species	PNCIMA Relevant Species
Gaviiformes (Loons)	Gaviidae (Loons)	4	Common Loon Yellow-billed Loon Pacific Loon Red-throated Loon
Podicipediformes (Grebes)	Podicipedidae (Grebes)	6	Pied-billed Grebe Horned Grebe Red-necked Grebe Western Grebe
Procellariiformes (Tube-noses)	Diomedidae (Albatrosses)	3	Black-footed Albatross Laysan Albatross Short-tailed Albatross
	Procellariidae (Fulmars and Shearwaters)	9	Northern Fulmar Pink-footed Shearwater Flesh-footed Shearwater Buller's Shearwater Sooty Shearwater Short-tailed Shearwater Manx Shearwater
	Hydrobatidae (Storm-petrels)	2	Fork-tailed Storm-petrel Leach's Storm-petrel
Pelecaniiformes (Totipalmate swimmers)	Phalacrocoracidae (Cormorants)	3	Double-crested Cormorant Brandt's Cormorant Pelagic Cormorant
Ciconiiformes (Bitterns, Herons, Egrets, and Allies)	Ardeidae (Bitterns and Herons)	9	Great Blue Heron
Anseriformes (Waterfowl)	Anatidae (Swans, Geese, and Ducks)	45	Tundra Swan Trumpeter Swan Greater White-fronted Goose Snow Goose Brant Canada Goose Wood Duck Green-winged Teal Mallard Northern Pintail Blue-winged Teal Northern Shoveler Gadwall American Wigeon Canvasback Greater Scaup Lesser Scaup Harlequin Duck Long-tailed Duck Black Scoter Surf Scoter White-winged Scoter Common Goldeneye Barrow's Goldeneye Bufflehead Hooded Merganser Common Merganser Red-breasted Merganser
Falconiformes (Diurnal Birds of Prey)	Accipitridae (Ospreys, Eagles, Hawks, and Allies)	12	Osprey Bald Eagle
	Falconidae (Falcons)	6	Peregine Falcon

Figure K.1 Taxonomy of marine-associated birds that use the PNCIMA area.

Order	**PNCIMA Relevant Families**	**# BC Species**	**PNCIMA Relevant Species**
Gruiformes (Cranes, Rails, and Allies)	Gruidae (Cranes)		Sandhill Crane
Charadriiformes (Shorebirds, Gulls, Auks, and Allies)	Charadriidae (Plovers)	5	Black-bellied Plover Semi-palmated Plover Killdeer
	Haematopodidae (Oystercatchers)	1	Black Oystercatcher
	Scolopacidae (Sandpipers, Phalaropes, and Allies)	44	Greater Yellowlegs Lesser Yellowlegs Wantering Tattler Spotted Sandpiper Whimbrel Ruddy Turnstone Black Turnstone Surfbird Sanderling Western Sandpiper Least Sandpiper Baird's Sandpiper Pectoral Sandpiper Rock Sandpiper Dunlin Short-billed Dowitcher Long-billed Dowitcher Common Snipe Red-necked Phalarope Red Phalarope
	Laridae (Jaegers, Skuas, Gulls, and Terns)	30	Pomarine Jaeger Parasitic Jaeger Long-tailed Jaeger South polar Skua Bonaparte's Gull Mew Gull California Gull Herring Gull Thayer's Gull Glaucous Gull Glaucous-winged Gull Black-legged Kittiwake Sabine's Gull Caspian Tern Common Tern Arctic Tern
	Alcidae (Auks)	13	Common Murre Thick-billed Murre Pigeon Guillemot Marbled Murrelet Ancient Murrelet Xantus' Murrelet Cassin's Auklet Rhinoceros Auklet Tufted Puffin Horned Puffin
Passeriformes (Perching Birds)	Corvidae (Jays, Magpies, and Crows)	9	Northwestern Crow Common Raven

Figure K.1 continued…

3.0 OVERVIEW OF MARINE BIRDS

3.1 Occurrence and Distribution – Breeding Birds

3.1.1 Seabirds

Seabirds are widely distributed in coastal BC and in PNCIMA, and use the area throughout the year. Approximately 40 species of pelagic seabirds (including phalaropes) occur within the region at some time during the year; fifteen of these species breed in BC, and fourteen breed within PNCIMA. In 1991, it was estimated that over 5.6 million birds nest at 503 known sites (mostly small islands) along the coast of BC (Rodway 1991).

PNCIMA supports 95% of BC's total breeding seabird population, which tends to be concentrated around the Scott Islands, Gillam Island in Quatsino Sound, Solander Island north of Brooks Peninsula, islands in the mouth of Queen Charlotte Strait, and around the Queen Charlotte Islands/Haida Gwaii (Figure K.2). In addition, important seabird aggregations are supported in numerous small colonies along the BC coast, including along the east coast of Moresby Island, and along the west coast of Moresby and Graham islands (see Figure K.22); these aggregations have functional importance equal to any large seabird colony (M. Hipfner, Environment Canada, Canadian Wildlife Service, Delta BC, pers. comm., 2006).

Specifically, PNCIMA supports all of BC's nesting Ancient Murrelets (all on the Queen Charlotte Islands); over 99% of BC's nesting Fork-tailed Storm-petrels, Cassin's Auklets, Rhinoceros Auklets, and the Horned and Tufted Puffins; roughly 97% of BC's Leach's Storm-petrels; and 85% of the Pigeon Guillemots (Rodway 1991). Colony population data for 10 of the 13 species that breed within the PNCIMA region have been mapped from site-specific surveys conducted during the 1980s (Figures K.3-K.11). The Canadian Wildlife Service (CWS) is in the process of updating colony data, including locations of colonies, census, and trends for seabird colonies on the coast of BC (see Figure K.22, section 8.2).

A recent synthesis and review of existing Marbled Murrelet data suggests that the majority of the BC population is likely concentrated in southern coastal BC and Vancouver Island. However, the same review estimates that up to 40% of the BC population may reside along BC's central and northern coast and on the Queen Charlotte Islands/Haida Gwaii (Burger 2002).

Status and trends of BC's breeding seabirds are outlined in Table K.0

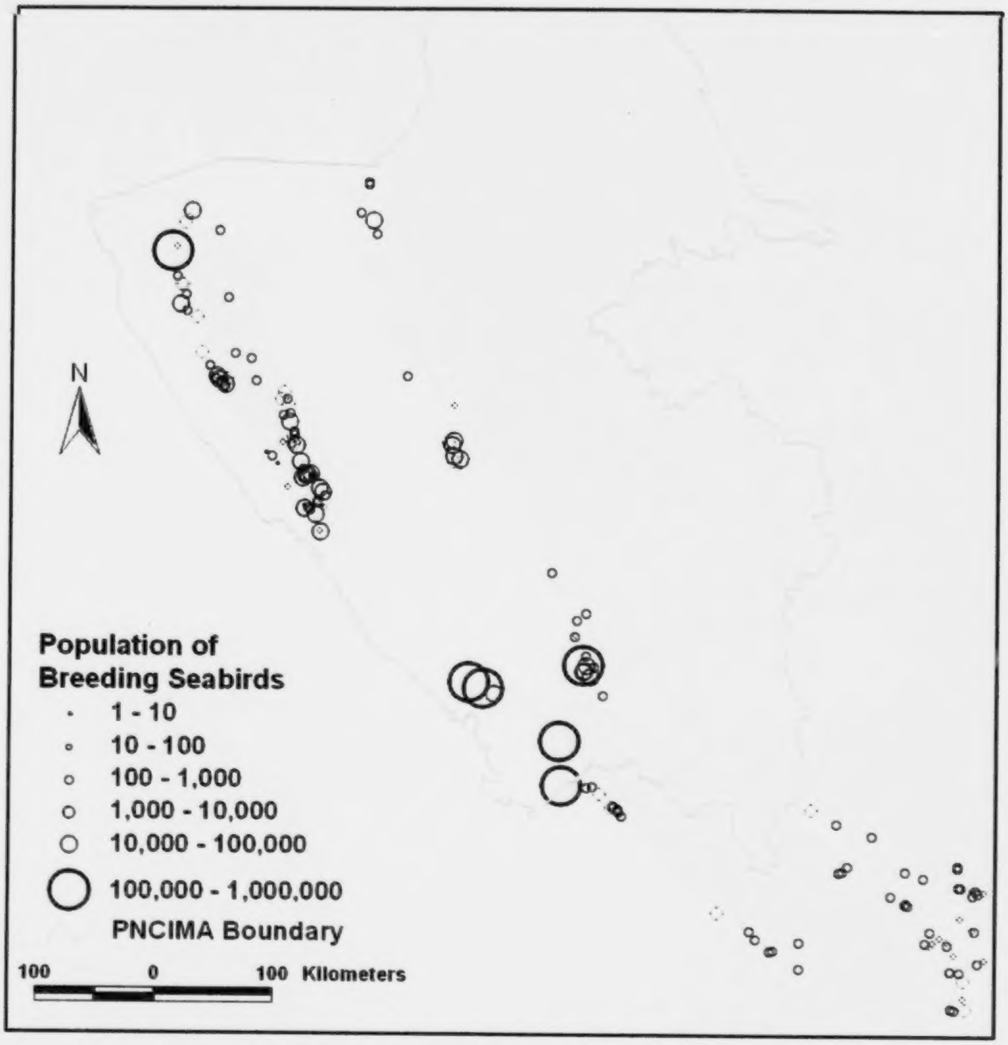
N
Population of Breeding Seabirds
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100
0
100 Kilometers

Figure K.2 Known nesting colonies of breeding seabirds (species pooled) in Canada's Pacific waters. PNCIMA region supports 95% of all seabirds nesting in BC (data from Rodway 1991).

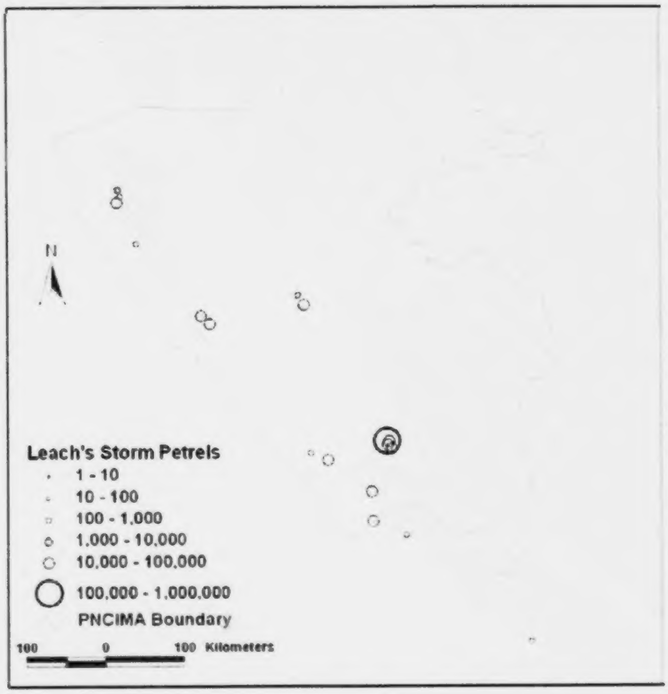
N
Leach's Storm Petrels
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100
0
100 Kilometers

Figure K.3 Known nesting colonies of Leach's Storm-petrels in Canada's Pacific waters. The PNCIMA region supports roughly 97% of western Canada's Leach's Storm-petrel breeding population (data from Rodway 1991).

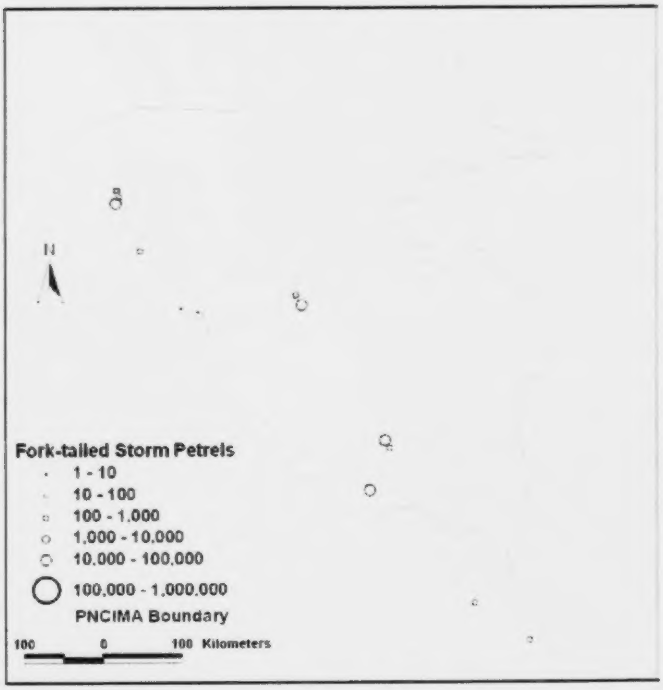
N
Fork-tailed Storm Petrels
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100
0
100 Kilometers

Figure K.4 Known nesting colonies of Fork-tailed Storm-petrels in Canada's Pacific waters. The PNCIMA region supports over 99% of Canada's Fork-tailed Storm-petrel breeding population (data from Rodway 1991).

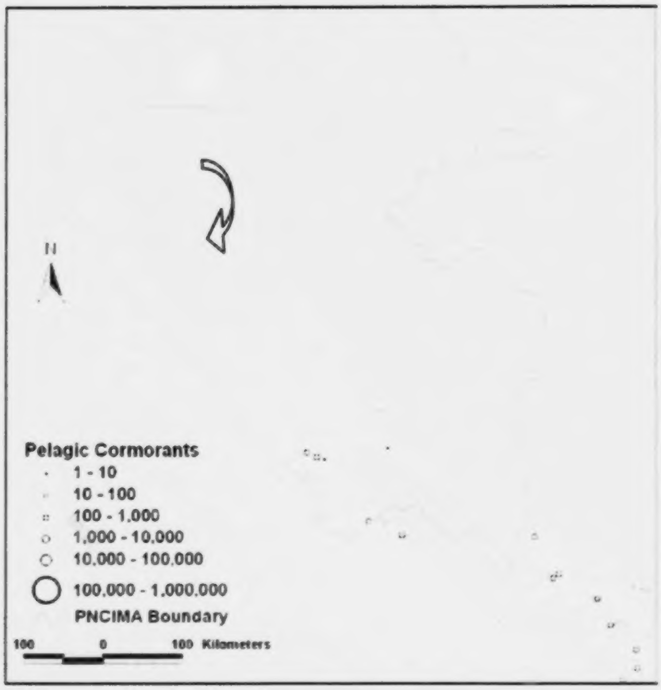
N
Pelagic Cormorants
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100
0
100 Kilometers

Figure K.5 Known nesting colonies of Pelagic Cormorants in Canada's Pacific waters. The PNCIMA region supports roughly 35% of Canada's Pelagic Cormorant breeding population (data from Rodway 1991). Arrow indicates additional small colonies along east coast of Moresby Island that were not mapped by Rodway 1991 (see Figure K.22).

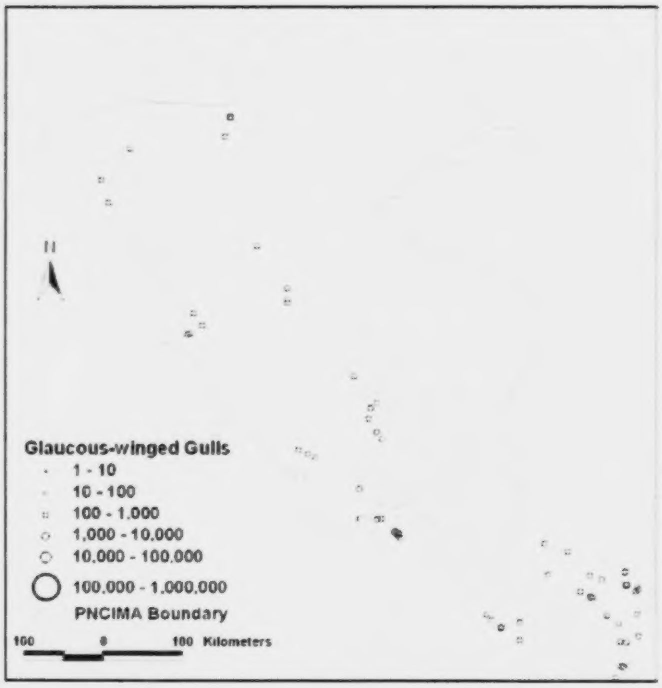
N
Glaucous-winged Gulls
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100
0
100 Kilometers

Figure K.6 Known nesting colonies of Glaucous-winged Gulls in Canada's Pacific waters. The PNCIMA region contains roughly 31% of Canada's breeding population (data from Rodway 1991). Note: Small colonies (<100 birds) were probably not counted by Rodway 1991 (M. Hipfner, Environment Canada, CWS, Delta BC, pers. comm., 2006); many more small colonies throughout PNCIMA are likely to be present, but not indicated on this figure.

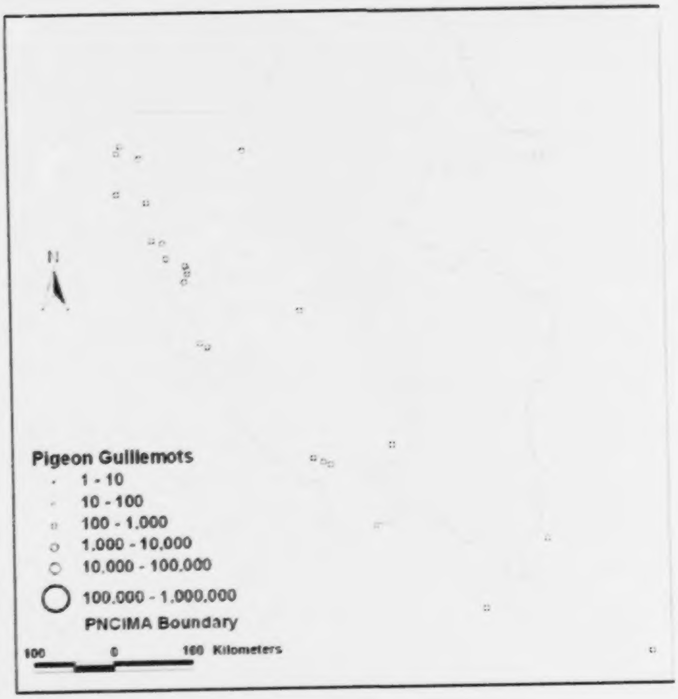
N
Pigeon Guillemots
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100 0 100 Kilometers

Figure K.7 Known nesting colonies of Pigeon Guillemots in Canada's Pacific waters. The PNCIMA region supports roughly 85% of Canada's Pigeon Guillemot breeding population (data from Rodway 1991).

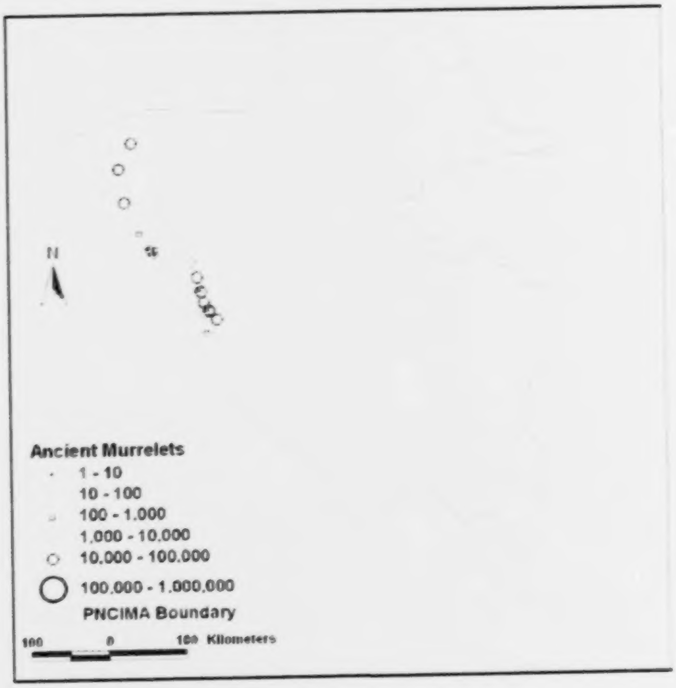
N
Ancient Murrelets
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100 0 100 Kilometers

Figure K.8 Known nesting colonies of Ancient Murrelets in Canada's Pacific waters. The PNCIMA region supports all of the known Ancient Murrelet breeding colonies in Canada (data from Rodway 1991).

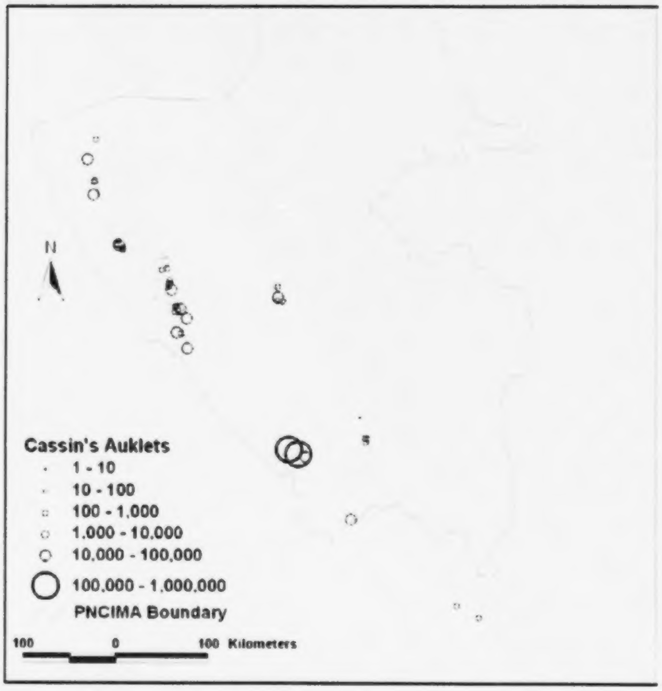
N
Cassin's Auklets
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100 0 100 Kilometers

Figure K.9 Known nesting colonies of Cassin's Auklets in Canada's Pacific waters. The PNCIMA region supports over 99% of Canada's Cassin's Auklet breeding population; 73% is found in the Scott Islands (data from Rodway 1991).

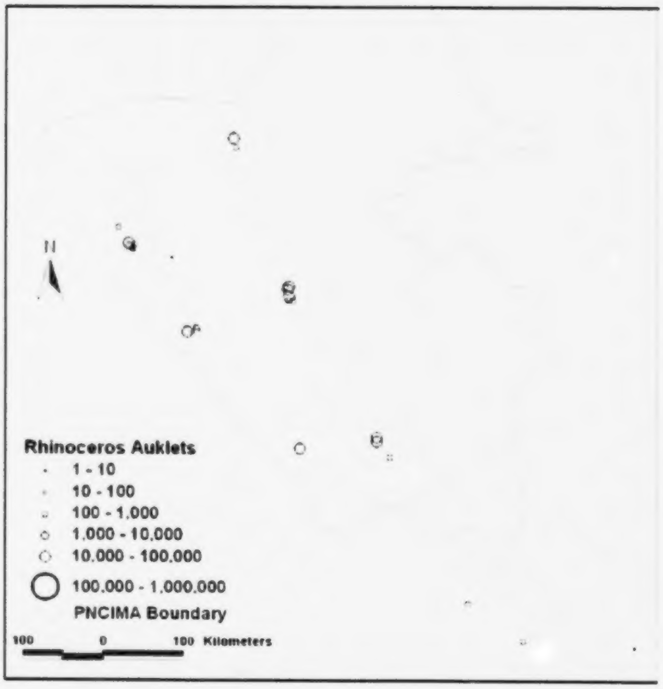
N
Rhinoceros Auklets
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100 0 100 Kilometers

Figure K.10 Known nesting colonies of Rhinoceros Auklets in Canada's Pacific waters. The PNCIMA region supports over 99% of Canada's Rhinoceros Auklet breeding population (data from Rodway 1991).

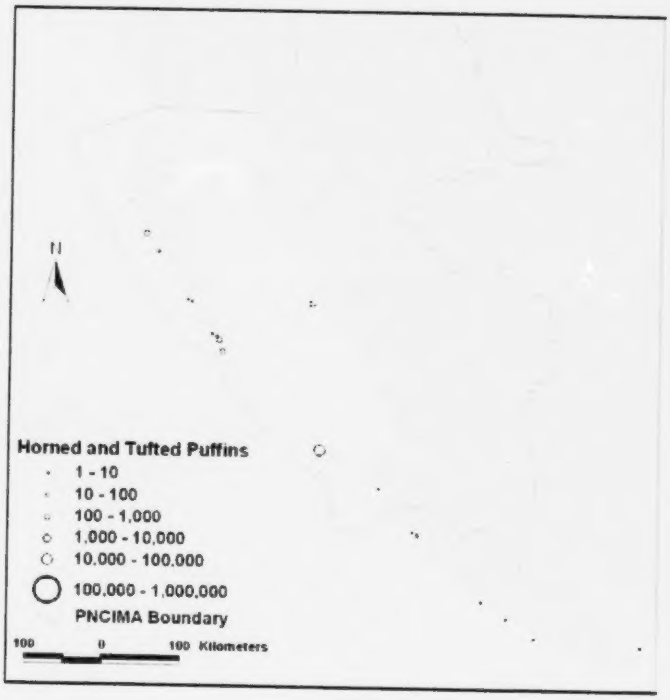
N
Horned and Tufted Puffins
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 1,000,000
PNCIMA Boundary
100 0 100 Kilometers

Figure K.11 Known nesting colonies of Horned and Tufted Puffins in Canada's Pacific waters. The PNCIMA region supports over 99% of Canada's Horned and Tufted Puffin breeding population; roughly 90% of provincial Tufted Puffins occur on the Scott Islands (data from Rodway 1991).

Table K.0 Status and trend of BC-breeding seabirds (table modified from Milko *et al.* 2003, unless otherwise indicated[3]).

Species (a = species found on both east and west coasts; b = species on west coast only)	**Estimated Population in North America**	**Canadian population as % of North American**	**Population Trend[1]**	**Conservation Category[2]**
Leach's Storm-petrel[a]	15, 275, 000 breeders	30-50%	4	High
Fork-tailed Storm-petrel[b]	5-6 million breeders	<10%	1	Not at risk
Pelagic Cormorants[b]	<69,000 breeders	<10%	4	High
Glaucous-Winged Gull[b]	380,000 breeders	10-30%	3	Low
Common Murre[a]	4,250,000 birds	10-30%	2	Low
Common Murre[b]			4[3]	High[3]
Pigeon Guillemot[b]	<69,000 breeders	30-50%	4	Moderate
Marbled Murrelet[b]	300,000-800,000 birds	10-30%	5	High
Xantus' Murrelet[b]	6,000-7,000 breeders	<10%	4	High
Ancient Murrelet[b]	1.3 million breeders	30-50%	3[3]	High
Cassin's Auklet[b]	3.2-3.6 million breeders	>70%	4[3]	High[3]
Rhinoceros Auklet[b]	922,000 breeders	30-50%	3[3]	Moderate[3]
Tufted Puffin[b]	2.75-3.0 million breeders	<10%	4	Moderate
Horned Puffin[b]	1 million breeders	<10%	3	High

[1] **Population Trend:** 5 = biologically significant population decline; 4 = apparent population decline; 3 = apparently stable population; 2 = apparent population increase; 1 = biologically significant population increase (Milko *et al.* 2003).

[2] **Conservation Category**: High = populations of these species are known or thought to be declining, and have some other known or potential threat as well. Moderate = populations of these species are either a) declining with moderate threats or distributions, b) stable with known or potential threats and moderate to restricted distributions, or c) relatively small with restricted distributions. Low = populations are either a) stable with moderate threats and distributions; b) increasing or of moderate size, but with known or potential threats and moderate to restricted distributions (Milko *et al.* 2003).

[3] Milko *et al.* (2003) data modified based on Hipfner (2005), and CWS unpubl. data.

3.1.2 Waterfowl and Allies

Coastal areas of British Columbia are recognized for their regional and international importance for numerous species of coastal waterfowl. The province's thirty-six species of waterfowl and allies are abundant along the coast of BC and in PNCIMA, particularly in estuaries, tidal flats, and near-shore protected habitats. Because most waterfowl breed inland or in the Arctic, BC's marine habitat is most important in providing major staging areas and critical habitats for wintering, moulting, and migrating waterfowl. Thus, occurrence and distribution of waterfowl is discussed more thoroughly in section 3.3 (marine habitat use).

3.1.3 Shorebirds

Shorebirds are widely distributed in PNCIMA and use the area primarily as winter visitants or for migration. Only two shorebird species, the Black Oystercatcher and the Great Blue Heron, are year-round residents and breed in coastal BC.

The Black Oystercatcher is widespread along the BC coast (Rodway 1991), and is one of the principal indicator species of nearshore ecosystem health (Andres and Falxa 1995; USDA Forest Service 2002). Black Oystercatchers are intimately associated with rocky intertidal ecosystems and in the past, have been recorded nesting over at least 80% of the province's shoreline (Campbell *et al.* 1990a; 1990b). Because much of PNCIMA shoreline is rocky, it is likely safe to assume that most of the shoreline in PNCIMA is suitable habitat for Black Oystercatchers. Localized surveys have identified nesting sites in PNCIMA at Triangle Island, the entrance to Queen Charlotte Strait, off Aristazabal Island (Jacqueline Booth and Associates *et al.* 1998), and on 77 islands along the coasts of Gwaii Haanas National Park and northern Haida Gwaii (M. Hipfner, unpublished data). Additionally, nest sites have been identified on 76 islands within Pacific Rim National Park and Gulf Islands National Park (M. Hipfner, unpublished data; see also nest sites compiled by Ardron 2003; Figure K.12).

Two subspecies of Great Blue Heron occur in BC; *Ardea herodias fannini* is resident along the coast, and *A.h. herodias* breeds inland but winters along the Pacific Coast. The largest concentrations of Great Blue Herons occur in the Strait of Georgia/Georgia Depression ecoregion, because of large colonies nesting there (Campbell *et al.* 1990a; 1990b). North of Vancouver Island, heron nesting is sparse and there are no known colonies with more than 20 pairs (Fraser *et al.* 1999); however, potential habitat for herons (*A.h. fannini*) occurs throughout the BC coast (Vennesland 2004). Nesting has been confirmed along the coast in Campbell River, Squamish, Sunshine Coast, and the Queen Charlotte Islands (Vennesland 2004).

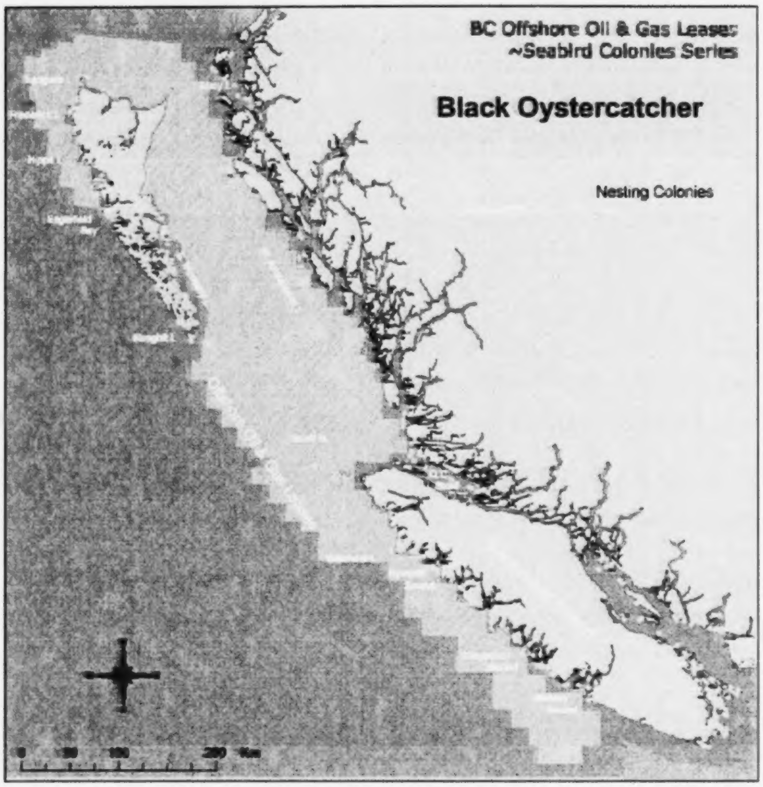

Figure K.12 Known nesting locations of the Black Oystercatcher in Canada's Pacific waters (map created by Ardron 2003).

The *fannini* subspecies in British Columbia is currently estimated at 3626 breeding adults, with an estimated 3326 adults breeding in the Strait of Georgia and 300 breeding elsewhere on the coast (Gebauer and Moul 2001). The size of the *herodias* subspecies population in British Columbia is not known, but probably ranges between 300 and 700 individuals (Gebauer and Moul 2001). Main causes of conservation concern for herons are disturbance from human activities and eagle predation of nestlings (Vennesland and Butler 2004).

3.2 Foraging Habitat Associated with Breeding

3.2.1 Seabirds

During the nesting season, seabirds forage at sea near their colonies; hence, these areas provide critical habitat for these birds at that time of the year.

Foraging areas around colonies are not precisely known. This is partly due to the ephemeral nature of the ocean system, which causes fluctuations in location and density of marine bird forage prey both within and between years; and partly due to the challenge of tracing seabirds to their foraging areas. However, using a number of techniques (radiotelemetry, *c.f.* McFarlane Tranquilla *et al.* 2005; satellite telemetry, *c.f.* Hyrenbach *et al.* 2002; isotopic signatures, *c.f.* Davies *et al.* 2004), the foraging range of seabirds from their colony can be determined (see Table K.1), and colony-based foraging areas can be extrapolated. Multiple years of data from single colonies are critical to extrapolating colony-based foraging areas, as these areas are likely to change annually due to variation in oceanographic processes (Bertram *et al.* 2001; McFarlane Tranquilla *et al.* 2005; see section 4.4).

Table K.1 Marine foraging ranges for nesting seabirds in Canada's Pacific waters. Superscripts refer to references for each species, cited below table.

Species	**Marine foraging range from breeding colonies**
Leach's Storm	>200 km[1]
Fork-tailed Storm-petrels	75-150 km[2]
Brandt's Cormorant	0-80 km[3]
Double-crested Cormorant	within 5 km[3]
Pelagic Cormorant	within a few km[3]
Black Oystercatcher	1 km[4]
Glaucous-winged Gull	up to 100 km[3]
Common Murre	up to 100 km[4]
Pigeon Guillemot	10 km[5]
Ancient Murrelet	adults stage within 1-3 km of colony[5]
Cassin's Auklet	55-80 km[6,7]
Rhinoceros Auklet	20-87 km[7,8]
Tufted Puffin	within 100 km[9]
Horned Puffin	10-110 km[10]

1) Huntington *et al.* 1996; (2) Boersma and Silva 2001; (3) Ainley and Boekelheide *eds.* 1990; (4) Andres and Falxa 1995; (5) Gaston and Jones 1998; (6) Ryder *et al.* 2001; (7) McFarlane Tranquilla *et al.* 2005; (8) Kato *et al.* 2003; (9) Piatt and Kitaysky 2002a; (10) Piatt and Kitaysky 2002b.

Radio telemetry is effective in determining foraging distances of breeding birds during shorter time-periods (*e.g.*, chick-rearing) and over shorter geographical range. For example, a four-year radiotelemetry study (CWS/Simon Fraser University in BC) determined how far Cassin's and Rhinoceros Auklets foraged from their colony at Triangle Island. The results showed that Cassin's Auklets foraged within an area 30-75 km southwest of Triangle Island in 1999 and 2000, and 55-80 km northwest of Triangle Island in 2001, in waters that were seaward of or over the continental shelf, from 330 to >1000 m deep (Ryder *et al.* 2001). They also found that Rhinoceros Auklets foraged 20-

70 km northwest of Triangle Island (2002). This study was the first to describe foraging areas used by auklets that nested at Triangle Island, and discovered an inter-annual shift in marine location of colony foraging area.

Satellite telemetry is more useful for tracking long-range movements of seabirds, for wide-ranging species (trans-equatorial migrants, for example), or across seasons. Several studies have employed this technique to track albatrosses covering foraging ranges of thousands of kilometres (Hyrenbach *et al.* 2002; Finkelstein *et al.* 2006).

A model was developed by Yen *et al.* (2004b), which predicts important Marbled Murrelet foraging area for the entire coast of BC. This model compared several murrelet habitat preferences and historical murrelet surveys to come up with predicted murrelet densities associated with those habitat features in areas that were not surveyed. This type of modelling-mapping approach will be useful to other seabird species which are difficult to find and/or which are spread over a large geographic area.

Maps of BC marine habitats used by breeding seabirds, based on seabird predicted foraging areas, have been created by Ardron (2003), for 13 colonially breeding species (pooled), the Cassin's Auklet, and the Marbled Murrelet. They can be found at http://www.livingoceans.org/maps/index.php?section=oog.

3.2.2 Waterfowl and Allies

See section 3.3

3.2.3 Shorebirds

Shorelines throughout PNCIMA provide critical habitat and foraging sites for both resident and migratory shorebirds. In particular, estuaries (see Figure K.12) are critical to shorebirds, providing beaches for foraging and roosting for resident, wintering, and migrant shorebirds. Foraging habitat associated with nesting will be relevant only to the two BC-breeding shorebirds in this group: the Black Oystercatcher and the Great Blue Heron.

Locations of known nesting areas of the Black Oystercatcher in BC have been mapped (Figure K.12; see also K.22). This species' nest sites are currently being censused and monitored (by CWS and Parks Canada; M. Hipfner, Environment Canada, CWS, Delta BC, pers. comm., 2006). Black Oystercatchers forage in the intertidal/littoral zone and maintain a mean territory size of 75 m during breeding (Hazlitt 2001).

Great Blue Herons forage in aquatic habitat such as tidal mudflats, riverbanks, lakeshores, and wetlands, and require foraging areas within 10 km of their coastal nesting sites (Butler 1992). There is only anecdotal information about Great Blue Heron distribution in PNCIMA. Small numbers have been noted in the Broughton Archipelago and Skidegate Inlet (Badzinski *et al.* 2005), and individuals have been observed in association with reefs and kelp beds along BC's central and north coasts.

3.3 Marine Habitat Use

The Pacific coastline of British Columbia provide not only diverse breeding and roosting habitat but also rich feeding grounds for millions of seabirds, both migrants and residents. Nesting habitat and roosting sites, free of disturbance and predators, are obviously critical to the survival of seabird species, yet marine habitat degradation and alteration also pose a serious threat to seabird populations in the region (Mills *et al.* 2005).

Although marine areas in close proximity to breeding sites are critical to marine birds (*i.e.*, see section 3.2), migration routes and moulting and wintering areas comprise a major component of marine habitat use for both resident and migrant marine birds.

A detailed summary of the distribution, habitat, feeding, and breeding habits of individual marine bird species relevant to PNCIMA can be found in Johannessen *et al.* (2005).

3.3.1 Seabirds

A recent assessment of non-breeding seabird populations of the North Pacific Ocean estimated that at least 550,000 seabirds used the marine environment off the BC coast from June through August. During the spring and fall, the number of birds that migrate through the area is estimated to be an order of magnitude greater (Hipfner *et al.* 2002). This highlights the importance of spring, fall, and winter surveys in addition to surveys at the breeding colonies.

Outside the breeding season, BC breeding seabirds, and seabirds from elsewhere, congregate on the open ocean off the BC coast. Many species of seabird show a preference for areas around the edges of shallow banks in Queen Charlotte Sound and areas of upwelling, such as along the continental shelf break (Figure K.13; see also Chapter 1, section 1.4 and 1.4.1, and Appendix D: Plankton for a description of local spatial processes influencing plankton).

Generally, the greatest average marine bird densities along BC's west coast occur over the continental shelf (Morgan *et al.* 1991; Kenyon *et al.* in prep). Average marine bird density for the entire coast, including offshore pelagic areas and PNCIMA, has been calculated using data collected from marine surveys over a period spanning 24 years (1981-2005), in all seasons of the year. This data is being used to update the previous BC marine bird atlas (Morgan *et al.* 1991); the new atlas is intended for publication within a few months (J. Kenyon, CWS, Environment Canada, Ladner BC, pers. comm., 2006). Their findings on marine bird presence and density have briefly been incorporated into this summary (see Figures K.14-K.15; see also section 3.6).

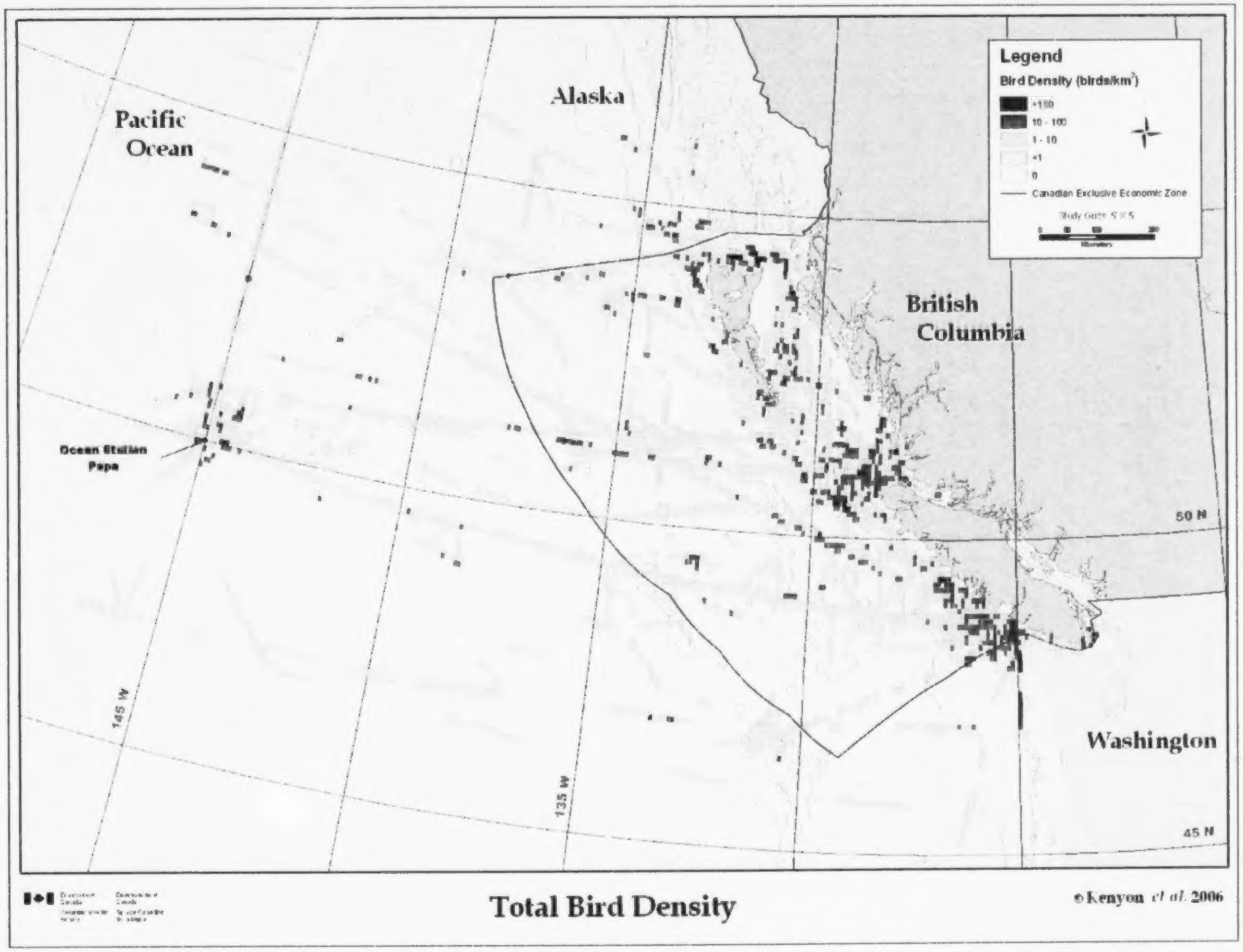
Pacific Ocean
Alaska
British Columbia
Washington
Ocean Station Papa
Legend
Bird Density (birds/km²)
+100
10 - 100
1 - 10
<1
0
Canadian Exclusive Economic Zone
Study Grids 5 X 5
Kilometers
50 N
45 N
145 W
135 W
Total Bird Density
©Kenyon et al. 2006

Figure K.13 Marine bird density from "Ship of Opportunity" at-sea surveys. Data collected 1983-2005 (CWS/K. Morgan). Courtesy of CWS, Kenyon *et al. in prep*.

CWS has data on year-round presence/abundance for 50 species of seabird using BC coastal and/or pelagic waters, including PNCIMA (Kenyon *et al.* in prep; see Figures K.14-K.15). Results from Kenyon *et al.* (in prep) show that PNCIMA contains many of the highest bird densities in coastal BC (Figure K.13). Because they are formatted for another report, Figures K.14-K.15 divide seabird abundance into north versus south of 52° latitude; this latitude bisects the PNICMA, so both figures are included here. Kenyon *et al.* (in prep) also describe seabird seasonal abundance in offshore areas; however, these maps were not included in this report because the designated offshore area, from the 500 m isobath out to 147 degrees west longitude, overlaps very little with PNCIMA (see Chapter 1: Ecosystem Description).

Species-specific habitat preferences are based on a variety of marine features, including sea surface temperature (some like it cold, some like it hot), bathymetric features (shallow, near land, near shelf breaks, or away from shelf breaks), cholorophyll *a* (varying concentrations), and areas of upwelling (varying distance from; Morgan *et al.* 1991; Reifenstein and Huettmann 2004; Yen *et al.* 2005; Batten *et al.* 2006). Knowledge of any species distribution must include an understanding of their marine preferences; and likewise, this knowledge is critical to predicting how changes in ocean climate affect the delineation between coastal and oceanic ecosystems and the seabirds residing in each system (Yen *et al.* 2005).

Beginning in 1996, CWS, with DFO and Coast Guard support, began surveying seabirds and marine mammals along what is known as Line P, a transect running from south of Vancouver Island, west to Ocean Station Papa (see Figure K.24). Line P data was incorporated into the CWS BC marine bird atlas (Kenyon *et al.* in prep), mentioned above. An analysis of Line P data examined the annual and interannual variation in marine bird community structure from the coastal to pelagic system (Yen *et al.* 2005); the results showed distinct spatial separation of seabird species groups (Table K.2), and allow an analysis of seabird habitat preferences, which appear to vary as a function of ocean climate.

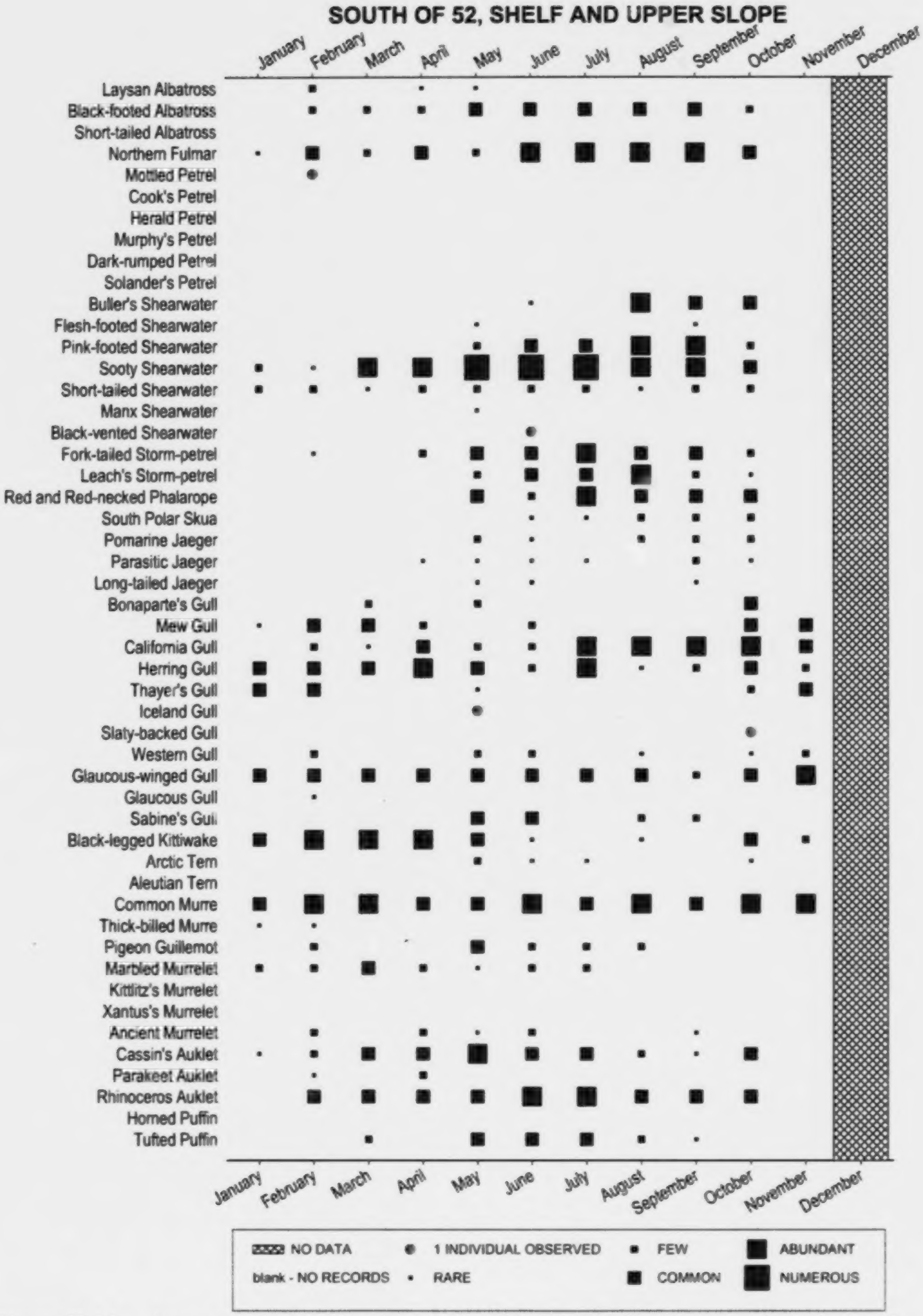

Figure K.14 Average relative abundance of seabirds in shelf and upper slope (coastal) waters of BC, **south** of 52° latitude. Red dots indicate species with only a single individual observed within that sub-region. Courtesy of CWS (Kenyon *et al. in prep*).

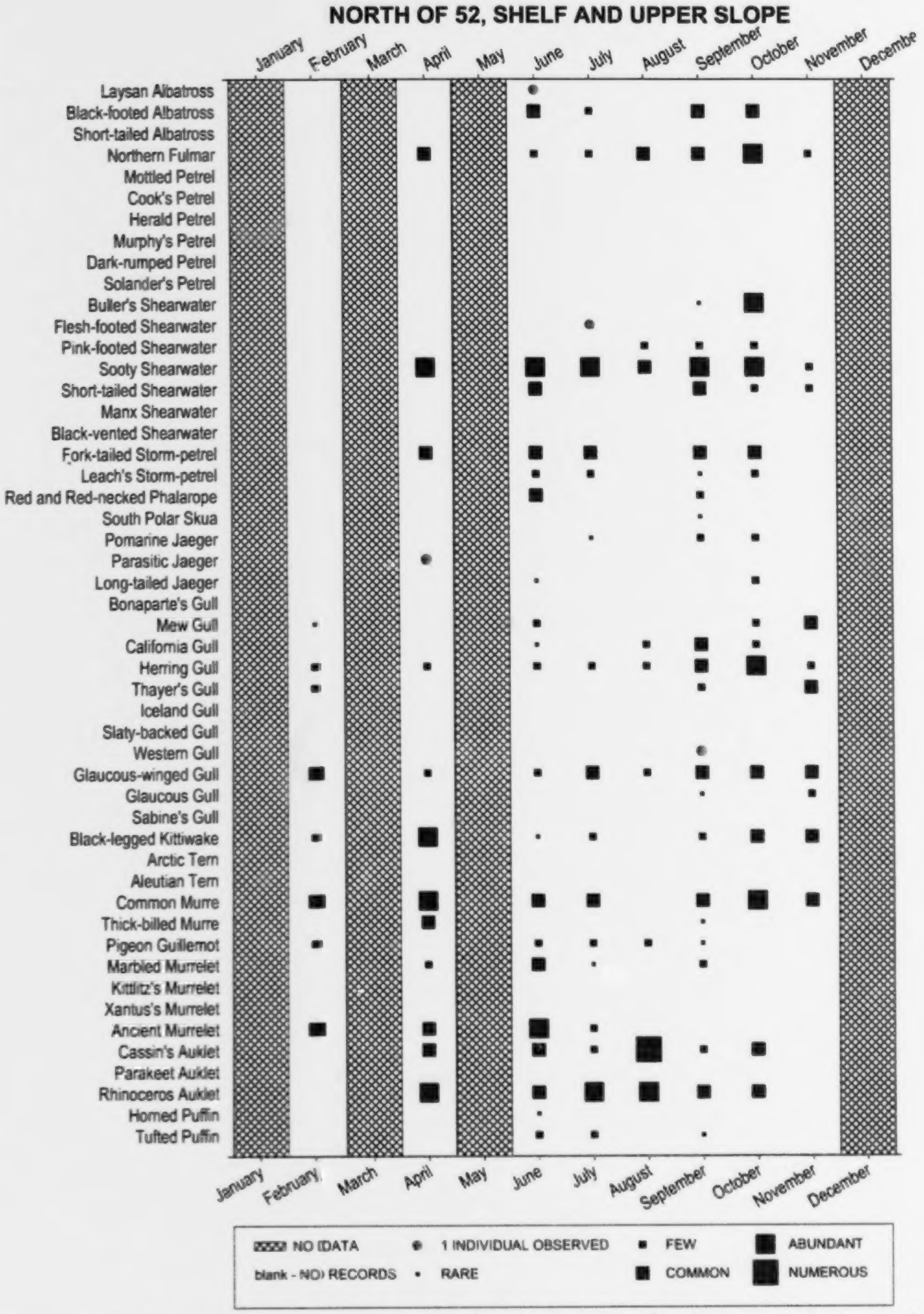

Figure K.15 Average relative abundance of seabirds in shelf and upper slope (coastal) waters of BC, **north** of 52° latitude. Red dots indicate species with only a single individual observed within that sub-region. Courtesy of CWS (Kenyon *et al. in prep*).

Table K.2 Habitat preferences of seabirds recorded during surveys conducted along the Line P (Ocean Station Papa) route (Yen *et al.* 2004a; 2005).

Seabird Group/Species	Habitat Preferences
Alcids	most prevalent in coastal regions; highest densities near the continental shelf break; except Tufted Puffin, which occurred throughout Line P, and showed differences in density between coastal and pelagic waters.
Shearwaters, Fulmars	occurred in both coastal and pelagic waters, but mostly restricted to the coastal region over the continental shelf.
Jaegers, Skuas	occurred in both coastal and pelagic ecosystems but were found primarily seaward of the shelf in areas with flat bathymetry.
Black-footed Albatross	occurred throughout Line P but most numerous over shelf break.
Phalaropes	occurred only in coastal regions; greatest densities were close to land and over variable bathymetry.
Storm-petrels	most common in coastal regions but highest densities were over deepest pelagic waters.
Gulls	predominantly in coastal areas; occurred in highest densities over the continental shelf.

3.3.2 Waterfowl and Allies

BC marine habitat provides major staging areas and critical habitats for wintering, moulting, and migrating waterfowl. Important habitats within these stretches include estuaries that are used by nesting waterfowl for foraging; sheltered inlets and archipelagos used by overwintering sea ducks; and more exposed, outer coastal sites used by post-breeding, moulting sea ducks in late summer (Jacqueline Booth and Associates *et al.* 1998). Waterfowl are abundant along the coast of BC and in PNCIMA.

- There are over 100,000 dabbling ducks known to winter in coastal estuaries and agricultural habitats of British Columbia. Mallard, American Wigeon, Northern Pintail and Green-winged Teal are the most abundant species (Butler 1992).
- Preliminary surveys conducted on the east and west coasts of Vancouver Island suggest that there are hundreds of thousands of seaducks wintering in coastal habitats, primarily scoters and goldeneyes (Gebauer 2003).
- Limited surveys suggest that there are tens of thousands of diving ducks, primarily Lesser and Greater Scaup, wintering in BC coastal waters (Gebauer 2003).
- Approximately 50% of the Pacific Coast population of Trumpeter Swans winter in southwest British Columbia, primarily in the Strait of Georgia, and this population has been increasing in recent years (Gebauer 2003).

- Approximately half of the Russian population of Lesser Snow Goose nesting on Wrangel Island, Russia, winters in the Fraser River delta. This wintering population has been increasing in recent years and it now amounts to roughly 60,000 birds (Gebauer 2003).
- An estimated 1,800 Pacific Brant (*Branta bernicla nigricans*) winter along the BC coast (*i.e.*, 1200 in Boundary Bay, 400-600 in the Queen Charlotte Islands, 50 on Sidney Island, and 10 in Baynes Sound), and several Western High Arctic Brant (*B. bernicla hrota*) now winter in the Fraser River delta. These numbers represent less than 1% of the Pacific coast population of Pacific Brant and 3% of the entire Western High Arctic Brant population (Gebauer 2003).
- During winter surveys, Surf Scoters, White-winged Scoters, and Harlequin Ducks were the most common moulting ducks along the BC coast; and Surf Scoters comprised over 95% of birds recorded along the mainland coast (Boyd and Breault 2002).
- The largest concentrations of moulting scoters were recorded at Observatory Inlet just south of the BC-Alaska border, and evidence suggests that this area may be a traditional moulting site (Boyd and Breault 2002).
- Other species known to moult in large numbers in Canada's Pacific waters include the Black Scoter, Long-tailed Duck, and Greater Scaup (Savard 1988).
- The west coast of Vancouver Island provides important winter and spring foraging areas for scoters and other sea ducks (an average of 30,000 birds per survey), in association with herring spawn (Breault *et al.* 2002) (see section 4.3).
- Christmas Bird Counts identified several areas of PNCIMA as important for wintering waterfowl, including the mouth of Queen Charlotte Sound, Skidegate Inlet, and Rose Spit (*e.g.*, Barrow's Goldeneye, Bufflehead, Brant, Black Scoter, Common and Hooded Mergansers, Harlequin Ducks, Long-tailed Duck; Badzinski *et al.* 2005). The selection of these three important sites does not imply that other coastal areas in PNCIMA were not important, just that those sites were not surveyed. This is because Christmas Bird Count sites are not selected at random, but are monitored by volunteers who live nearby (Badzinski *et al.* 2005); thus, counts are likely to be highest where sites coincide with high density of people.

Data from a variety of sources was used to create maps of important habitat for waterfowl, in general (Figure K.16), and for moulting scoters and Harlequin Ducks (Figures K.17-K.18; Ardron 2003). A number of these sites occur within PNCIMA. Waterfowl are limited in their ability to fly while moulting; hence, areas used during the moulting period comprise critical habitat for these birds. Due to their reliance on nearshore foraging habitat in estuaries, the Pacific Estuary Conservation Program (PECP) estuary mapping project is of particular importance to waterfowl. The map of BC estuaries predicted to be important to waterfowl (and other marine birds) is presented here (Ryder *et al.* , in prep; Figure K.19).

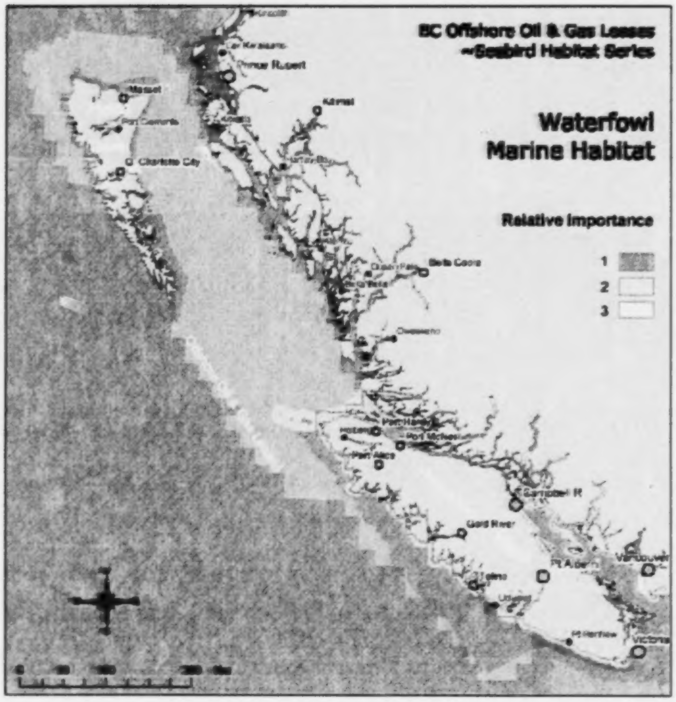
BC Offshore Oil & Gas Leases
~Seabird Habitat Series
Waterfowl
Marine Habitat
Relative Importance
1
2
3
Prince Rupert
Masset
Port Clements
Q. Charlotte City
Kitimat
Hartley Bay
Ocean Falls
Bella Coola
Bella Bella
Owekeno
Port Hardy
Holberg
Port McNeill
Port Alice
Campbell R
Gold River
Pt Alberni
Vancouver
Tofino
Ucluelet
Pt Renfrew
Victoria

Figure K.16 Locations of important marine habitat used by waterfowl (including ducks, swans, geese, grebes, and loons) in Canada's Pacific waters. The number '3' represents habitats of highest importance to these birds (map created by Ardron 2003).

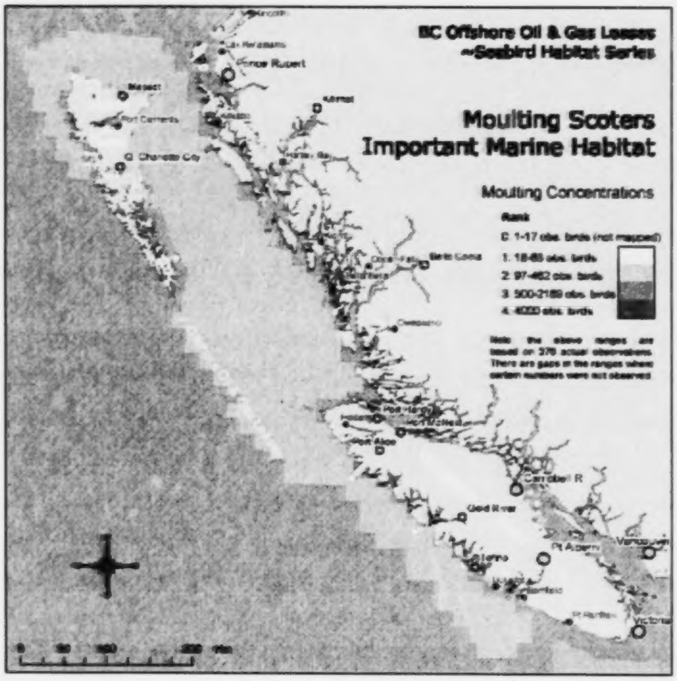
BC Offshore Oil & Gas Leases
~Seabird Habitat Series
Moulting Scoters
Important Marine Habitat
Moulting Concentrations
Rank
0: 1-17 obs. birds (not mapped)
1. 18-[illegible] obs. birds
2. 97-482 obs. birds
3. 500-2169 obs. birds
4. 4000 obs. birds
Note: the above ranges are based on 270 actual observations. There are gaps in the ranges where certain numbers were not observed.
Prince Rupert
Masset
Port Clements
Q. Charlotte City
Kitimat
Bella Coola
Port Hardy
Port Alice
Campbell R
Gold River
Pt Alberni
Vancouver
Tofino
Pt Renfrew
Victoria

Figure K.17 Locations of important marine habitat used by moulting scoters (3 species) in Canada's Pacific waters during summer (map created by Ardron 2003).

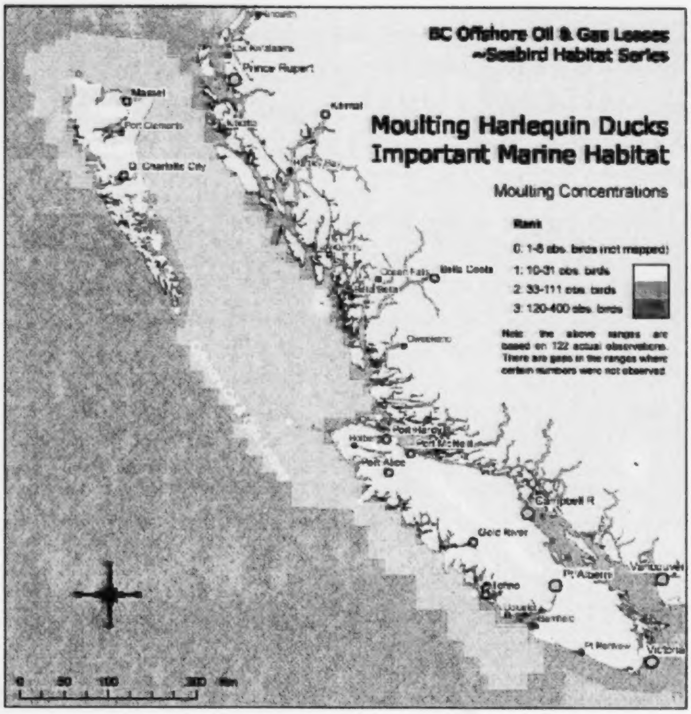
BC Offshore Oil & Gas Leases
~Seabird Habitat Series
Moulting Harlequin Ducks
Important Marine Habitat
Moulting Concentrations
Rank
0: 1-8 obs. birds (not mapped)
1: 10-31 obs. birds
2: 33-111 obs. birds
3: 120-400 obs. birds
Note: the above ranges are based on 122 actual observations. There are gaps in the ranges where certain numbers were not observed.
Masset
Port Clements
Q. Charlotte City
Prince Rupert
Kitimat
Bella Coola
Ocean Falls
Bella Bella
Port Hardy
Port McNeill
Port Alice
Campbell R
Gold River
Pt Alberni
Tofino
Vancouver
Pt Renfrew
Victoria
0 50 100 200 km

Figure K.18 Locations of important marine habitat used by moulting Harlequin Ducks in Canada's Pacific waters during summer (Ardron 2003).

3.3.3 Shorebirds

Due to their habitat associations with mudflats, beaches, and rocky intertidal zones, shorebirds are predictably associated with estuaries along the BC coast. A map of BC estuaries predicted to be important to shorebirds, is presented here (Ryder *et al.*, in prep; Figure K.19). The importance of small estuaries, harbours, and shallow inlets (*e.g.*, Englishman River, Bella Coola, Kitsault, and Tlell rivers, Comox Harbour, and Masset and Skidegate inlets) to migratory and wintering shorebirds has not been well documented; however, all estuarine habitats along the BC coast are likely part of a network of staging sites for migratory shorebirds. These smaller mudflat areas, when taken together, could support a substantial number of individuals (Gebauer 2003).

Shorebirds are supported in highest numbers in south central BC, particularly at the Fraser River Delta, Boundary Bay, Roberts Bank; and on the east coast of Vancouver Island from Nanoose Bay north to the Comox estuary (Badzinski *et al.* 2005). However, significant numbers of wintering shorebirds have been observed elsewhere in the province, such as in the mouth of Queen Charlotte Sound (*e.g.*, Black Turnstone, Dunlin, Greater Yellowlegs), at Skidegate Inlet (Black Turnstone, Surfbirds), and Rose Spit at the northeastern end of Queen Charlotte Islands (Badzinski *et al.* 2005).

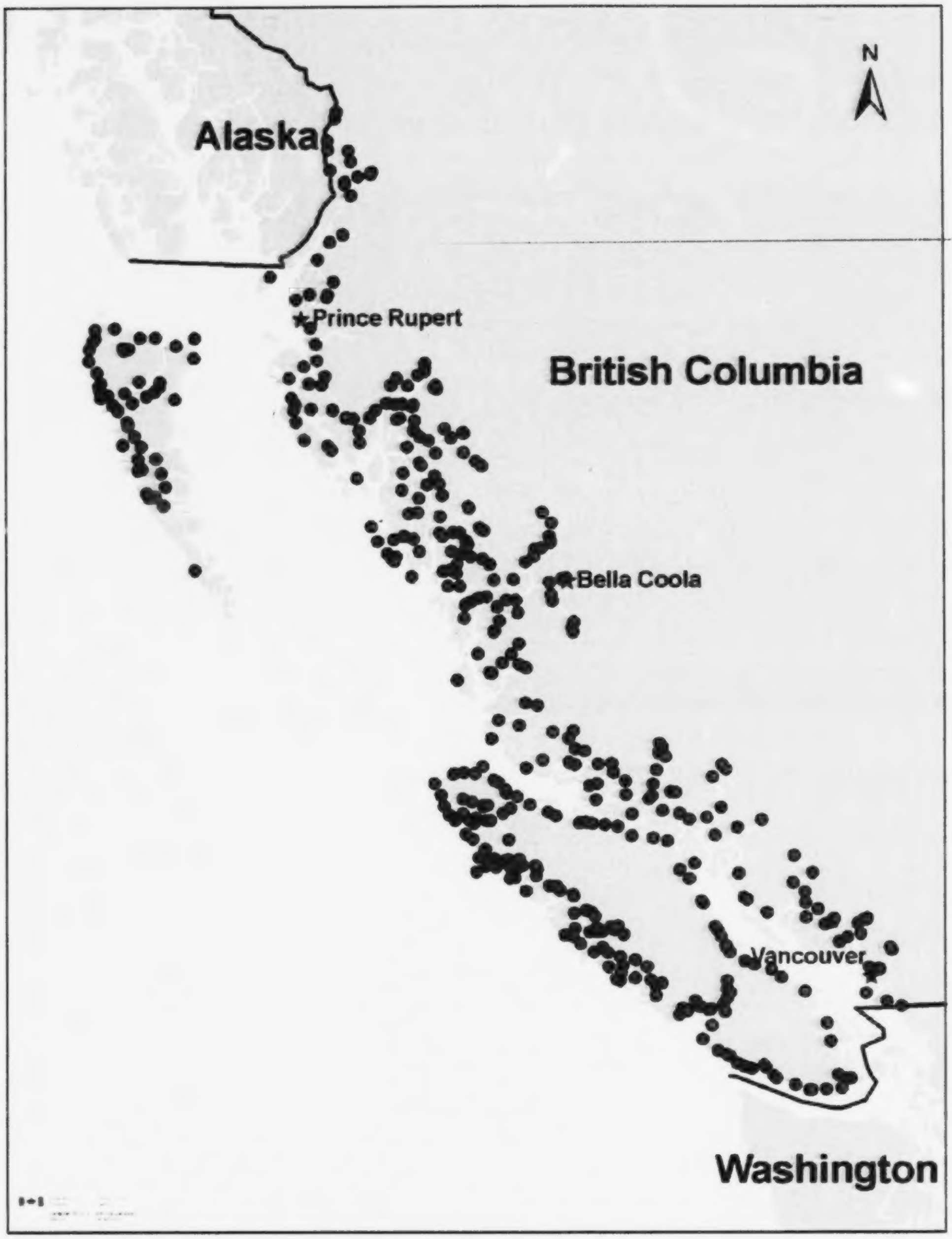
N
Alaska
Prince Rupert
British Columbia
Bella Coola
Vancouver
Washington

Figure K.19 Estuaries important to marine birds along the coast of BC. Each dot represents the location of one of the 442 PECP-identified estuaries. Courtesy of CWS (Ryder *et al.*, in prep).

3.4 Migration and Seasonal Movements

Monitoring the movements of bird species through a vast and remote region such as PNCIMA is difficult. However, several methods have been used to locate birds distributed widely across their marine habitat. These are: (1) bird surveys aboard ships of opportunity (*c.f.* Morgan *et al.* 1991), (2) satellite telemetry, (3) radio telemetry, (4) aerial surveys, and (5) monitoring migration stopover sites (see projects in section 8.0).

3.4.1 Seabirds

Long-distance foraging: Some species, notably albatross, do not breed in BC, but regularly use BC's pelagic waters for foraging throughout the year. For example, satellite telemetry has been used to track the movements of the Laysan Albatross and Black-footed Albatross from their breeding grounds in the Hawaiian Islands, as far as the BC coastline. Breeding Laysan Albatrosses commonly travelled as far as the Gulf of Alaska and back. Black-footed Albatrosses travelled to various points along the west coast, including British Columbia, and then followed the continental shelf northwards (Hyrenbach *et al.* 2002).

Analysis of satellite telemetry data can help identify spatial overlap between the movements of albatross and commercial fishing fleets in Alaska. Satellite telemetry can also be used to identify habitat preferences when species distributions are overlaid with remotely-sensed marine habitat variables (*e.g.*, sea surface temperature, chlorophyll, oceanographic or bathymetric features; Balogh and Suryan 2004).

Migration: There is a regular migration of phalaropes in the late summer along the central and north coast, including Queen Charlotte Sound and Queen Charlotte Strait, with a lesser number passing through Johnstone Strait. Large flocks are sometimes seen flying past Pine Island (R. Butler, Environment Canada, CWS, Ladner BC, pers. comm., 2006).

Seasonal Movements: Following the breeding season, resident seabirds must find a marine area for moulting and wintering. Birds are no longer tied to their colonies, so they can roam more freely across the marine environment. For most seabird species, the marine areas used during the fall and winter are not well known. Satellite telemetry can be used to identify the timing of movement and routes taken between different life stages and identify important stopover locations; it is currently the best tool to monitor a species over a vast and remote region such as PNCIMA.

3.4.2 Waterfowl and Allies

Migration and Seasonal Movements: The Sea Duck Joint Venture has undertaken satellite telemetry studies on Black, Surf and White-winged Scoters in coastal BC. The studies' objectives include identifying the species' migration routes, timing of movements, and moulting and wintering areas. A series of maps on the Venture's website (http://www.seaduckjv.org/ststoc.html) shows the movements of radio-tracked birds of all three species along the BC coast including PNCIMA. The US Geological Service has also used satellite telemetry to track movements of the Red-throated Loon and Northern Pintail, both of which have been found to migrate through the PNCIMA region.

3.4.3 Shorebirds

Migration: The migration route of most shorebirds in western North America is located over marine waters (Figure K.20), although some species make stopovers at suitable foraging sites along coastal shorelines (Warnock *et al.* 2001). The migratory species that use stopover sites in the PNCIMA region are mainly those that utilize rocky shorelines (*e.g.*, Surfbirds, Rock Sandpipers, and turnstones). Because most of the PNCIMA region's shoreline is rocky, the area provides few large stopover sites for those shorebird species that prefer mudflats or beaches.

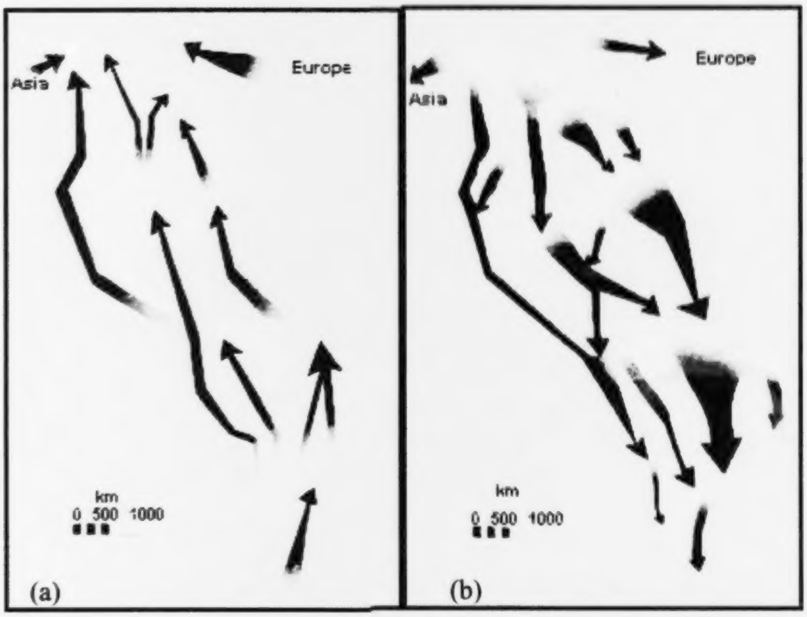

Figure K.20 General migration corridors of shorebirds in North America in (a) spring and (b) fall (Environment Canada 2001). The path along the west coasts of North and South America is called the Pacific Flyway.

3.5 Species of Conservation Concern

Thirty-three marine bird species or subspecies occurring in PNCIMA have been listed as species of conservation concern by the BC Conservation Data Centre, Committee on the Status of Endangered Wildlife in Canada (COSEWIC), *Species At Risk Act* (SARA), and/or the International Union for Conservation of Nature and Natural Resources (IUCN) (see details in Table K.3). These include 21 seabird species, 4 waterfowl species and 2 subspecies; 2 shorebird species and 2 subspecies; and 2 raptor species.

In addition to those waterfowl listed in Table K.3, it is worth noting that existing research suggests populations of many sea duck species are declining. Relative to some other species of waterfowl, sea ducks are long-lived, reach sexual maturity late in life and have low annual productivity. Of the sea duck species that visit PNCIMA, Long-tailed Ducks, all three species of scoter, Common Mergansers, and the Barrow's Goldeneyes are undergoing population declines. There are insufficient data to assess the population trends of other species such as Red-breasted Mergansers and Hooded Mergansers (Continental Technical Team 2003).

3.6 Management of Marine Birds

CWS is the federal agency responsible for the protection and management of migratory birds, nationally important wildlife habitat, and endangered species, and for research on nationally important wildlife issues (http://www.cws-scf.ec.gc.ca). Marine birds are afforded protection under the *Migratory Birds Convention Act* and the BC *Wildlife Act*.

As part of their continuous objective to manage migratory birds, CWS has identified a number of 'areas of interest' to migratory birds within the PNCIMA region. This project is currently under modification and review, to include updated marine bird information to 2005. It is intended for publication in 2007 and will be a crucial marine bird component to any planning initiatives that occur in PNCIMA (Kenyon *et al.* in prep; J. Kenyon, CWS, Environment Canada, Ladner BC, pers. comm., 2006).

Additionally, CWS and the PECP have collaborated to identify a number of estuaries within the region that provide important habitat for threatened or endangered bird species, and will be particularly relevant to waterfowl (see Ryder *et al.* in prep; Figure K.12).

Table K.3 Summaries for bird species in PNCIMA with a conservation designation[1,2].

Species	Use of BC coast and Canada's Pacific waters	Relevance to PNCIMA	Estimated Population	Status[3]			
				COSEWIC	SARA	BCCDC	IUCN
Seabirds							
Black-footed Albatross	Common visitor from the spring to fall.	Have been recorded in PNCIMA.	Between 2500 to 4000 birds visit BC annually.				EN
Laysan Albatross	Regular visitor to BC in low numbers.	Rare visitor to PNCIMA.	Probably no more than 200 birds visit BC annually.			B	VU
Short-tailed Albatross	Travel long distance from the breeding grounds to feed off the BC coast.	Have been recorded feeding in PNCIMA.	Breeding population in Japan is approximately 1,800.	T		R	VU
Northern Fulmar	Most breed in Alaska but occur year-round in BC waters; are common over shelf break and in pelagic waters.	Common in PNCIMA.	~ 1.4 million at colonies in eastern Pacific; but breeding population critically imperilled in BC.			R	LC
Flesh-footed Shearwater	Rare visitor to BC.	Rare visitor to PNCIMA.	Probably less than 100 visit BC annually.			B	
Manx Shearwater	Accidental visitor to BC.	Rare visitor to PNCIMA.	Unknown.			A	
Pink-footed Shearwater	Common visitor to BC.	Occasional visitor to PNCIMA.	Estimate of 20,000 or more present during summer and fall.	T		R	VU

Table K.3 continued…

Species	Use of BC coast and Canada's Pacific waters	Relevance to PNCIMA	Estimated Population	Status[3]			
				COSEWIC	SARA	BCCDC	IUCN
Black-vented Shearwater	Accidental visitor to BC.	Very rare visitor to PNCIMA.	Unknown.			A	VU
Buller's Shearwater	Common visitor to BC.	Very rare visitor to PNCIMA.	~ 5 - 10 thousand use BC waters.			B	VU
Double-crested Cormorant	Coastal breeder and overwinters in Canada's Pacific waters.	Not common in PNCIMA; no breeding recorded in PNCIMA.	4,000 breeding birds in BC.		NR	R	
Brandt's Cormorant	Coastal breeder and overwinters in Canada's Pacific waters.	Small breeding population in PNCIMA.	Winter population of 10,000-15,000. 190 birds breed in BC.			R	
Pelagic Cormorant (*pelagicus* subspecies)	Coastal breeder and overwinters in Canada's Pacific waters.	30% of BC's population breeds in PNCIMA.	9,000 birds breed in BC.			R	
Red-necked phalarope	Migrates through the interior and along the coast of BC.	Migrates through PNCIMA.	Migrates in the tens of thousands.			B	
California Gull	Large groups overwinter on Canada's Pacific waters; mostly along southern Vancouver Island.	Occasional visitor to PNCIMA.	Largest nesting colony known (130,000-150,000) around Great Salt Lake, Utah.			B	
Common Murre	Wide spread winter distribution, breeds on coastal islands.	Most of BC's population breeds in PNCIMA.	<7,000 breeding birds in BC.	LC		R	
Thick-billed Murre	Small breeding population on coastal islands.	Only know to breed in PNCIMA.	~ 2.4 million in North Pacific.	LC		R	

Table K.3 continued…

Species	Use of BC coast and Canada's Pacific waters	Relevance to PNCIMA	Estimated Population	Status[3]			
				COSEWIC	SARA	BCCDC	IUCN
Marbled Murrelet	Forages in inshore waters, rare offshore. Occurs year-round in BC waters.	Wide nesting distribution including PNCIMA.	~ 55, 000-78,000 along BC coast.	T	T	R	VU
Xantus' Murrelet	Accidental visitor to BC; encountered off southern Vancouver Island and WA state in fall and summer.	Observed south and west of Moresby Island in PNCIMA.	~ 7000 breeding in southern California/Mexico.			A	VU
Ancient Murrelet	Breeding colonies on Queen Charlotte Islands; some occurrence year-round in BC.	All BC population breeds on Queen Charlotte Islands in PNCIMA; some winter use of PNCIMA.	540,000 breeding birds in BC.	SC		B	
Cassin's Auklet	Coastal breeder and overwinters in Canada's Pacific waters.	>99% breed in PNCIMA region.	2.7 million birds breed in BC.			B	
Tufted Puffin	Coastal breeder and overwinters in Canada's Pacific waters.	Most of the 78,000 in BC, breed in PNCIMA.	~ 3.5 million in north Pacific.			B	
Horned Puffin	Suspected coastal breeder on 2 or 3 islands. Winters on outer coast.	Most BC breeders are in PNCIMA region.	60 birds breed in BC.			R	
Waterfowl							
Western Grebe	Large flocks overwinter.	Overwintering flocks arrive from western Canada and the northwestern United States. It is not known where breeding flocks overwinter.	Approximately 100,000 western grebes overwinter off the coast of BC, with known large concentrations in the southern Strait of Georgia.			R	

Table K.3 continued…

Species	Use of BC coast and Canada's Pacific waters	Relevance to PNCIMA	Estimated Population	Status[3]			
				COSEWIC	SARA	BCCDC	IUCN
Canada Goose (*leucopareia* and *occidentalis* subspecies)	Large flocks overwinter; also resident flocks year-round on BC coast.					B	
Long-tailed Duck	Overwinters in Canada's Pacific waters.	Overwinters in PNCIMA.	Overwintering populations number in the thousands.			B	
Surf Scoter	Overwinters in Canada's Pacific waters.		Over 60% of the worlds Surf Scoters overwinter in BC.			B	
Sandhill Crane	A few hundred *tobida* sp. breed along coast. *Canadensis* sp. migrates through.	It is possible that *tobida* sp. nest in central coast, while *Canadensis* sp passes over in migration.	3,500 use the coast during migration, few hundred breed along coast.			B	
Shorebirds							
Great Blue Heron (*fannini* subspecies)	Coastal breeder and overwinters in Canada's Pacific waters.	Widespread nesting distribution including PNCIMA.	*A.h. fannini* has a breeding population of 4000 in BC out of a world total of 10,000.	SC		B	
Great Blue Heron (herodias subspecies)	Overwinters in Canada's Pacific waters.	Winters in PNCIMA.	Estimated at 300-700 in BC.			B	
Wandering Tattler	Migrates along the coast of BC.	Migrates through PNCIMA.	Unknown numbers moving through PNCIMA.			B	
Short-billed Dowitcher	Migrates along the coast of BC.	Migrates through PNCIMA.	Large numbers migrate along coast.			B	

Table K.3 continued…

Species	Use of BC coast and Canada's Pacific waters	Relevance to PNCIMA	Estimated Population	Status[3]			
				COSEWIC	SARA	BCCDC	IUCN
Raptors							
Peregrine Falcon (*anatum* subspecies)	Breeding area includes the coast of BC.	Spring and fall migrant.	Rough estimate of 30 breeding pairs in BC.	T		R	
Peregrine Falcon (*pealei* subspecies)	Breeding area includes the coast of BC.	Less than 20% of the 200 birds that breed in BC.	200 breeding birds in BC.	SC		B	

[1] Additional information on population statistics, conservation status, and priorities of several waterbird species listed here can be found in **Canada's Waterbird Conservation Plan** (Milko *et al.* 2003).

[2] Table was compiled using information from: (1) BC Conservation Data Centre (BCCDC) 2006; (2) Morgan *et al.* 1991; (3) Kenyon *et al* in prep; (4) Environment Canada 2004; and (5) Burger 2002.

[3] **COSEWIC**: Committee on the Status of Endangered Wildlife in Canada. The designations refer to eastern Pacific populations. T = Threatened: a wildlife species likely to become endangered if limiting factors are not reversed; SC = Special Concern: particularly sensitive to human activities or natural events but not endangered or threatened. Special Concern was formally referred to as Vulnerable (Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2006; COSEWIC 2002).

SARA: *Species at Risk Act*, Schedule 1. T = Threatened: a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction; SC = Special Concern: a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats; NR = Not at Risk. (SARA 2006).

BCCDC: Provincial list of species of conservation concern in British Columbia. R = Red List: ecological communities, and indigenous species and subspecies that are extirpated, endangered, or threatened in BC; B = Blue List: ecological communities, and indigenous species and subspecies of special concern (formerly vulnerable) in BC; A = Accidental: species occurring infrequently and unpredictably, outside their usual range (BC CDC 2006).

IUCN Red List of Threatened Species: designations are for North American populations. EN = Endangered: a taxon is Endangered when the best available evidence indicates that it meets any of the criteria for Endangered, and it is therefore considered to be facing a very high risk of extinction in the wild; VU = Vulnerable: a taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria for Vulnerable, and it is therefore considered to be facing a high risk of extinction in the wild; NT = Near Threatened: a taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future; LC = Least Concern: does not qualify for CR, EN, VU or NT (IUCN 2004).

4.0 ECOSYSTEM LINKAGES

4.1 Prey Selection

Prey selection by marine birds varies geographically and temporally; it also varies among bird species and between juveniles and adults of the same species. Sympatrically-breeding species often show partitioning in foraging habitat use, foraging strategies, and prey selection (Croxall *et al.* 1997; Hobson *et al.* 1999; Lance and Thompson 2005; Ridoux 1994; Forero *et al.* 2004), both between species, and between reproductive stages (*e.g.*, pre-laying, nesting, chick-feeding; Davies *et al.* 2004).

Diet of marine birds varies widely among and within species, and can include fish (small age classes and eggs), molluscs, crustaceans, insects, marine worms, zooplankton, aquatic vegetation, carrion, and fish offal. Depending on the species, many seabirds feed at least in part, some entirely, on lower trophic levels (*i.e.*, zooplankton).

Despite this diversity, a few forage fish stand out as highly important prey items in the North Pacific, making up large portions of seabird diets. These are: Pacific herring (*Clupea pallasi*) (see Table K.4), sandlance (*Ammodytes hexapterus*), Pacific saury (*Cololabis saura*), and juvenile rockfish (*Sebastes* spp.; Robertson 1974; Hedd *et al.* 2006; Burger *et al.* 1993). The percentage of these species in the diets of adults and chicks has significant repercussions for reproductive success of many seabird species (Hedd *et al.* 2006).

Depending on the species, marine birds forage while sitting on the surface of the water, or dive to catch prey. Diving seabirds typically feed within the top 10 m of the ocean, although some species are capable of much deeper dives (Piatt and Nettleship 1985; Burger 1991). It has been suggested that deeper-diving seabirds are able to access a greater range of prey in years when prey availability is limited, and thus have a higher breeding productivity, compared to shallow divers or surface feeders (Hatch and Hatch 1990; Carscadden *et al.* 2002).

Table K.4 Marine bird species found in PNCIMA which prey on Pacific herring (*Clupea pallasi*; adapted from Gillespie and Westrheim 1997 in Vermeer and Morgan *eds*. 1997).

	Life stage of Pacific herring	
Bird Species	**Eggs/ larvae**	**Juveniles/ adults**
Red-throated Loon		*
Pacific Loon		*
Horned Grebe		*
Red-necked Grebe		*
Western Grebe		*
Sooty Shearwater		*
Double-crested Cormorant	*	*
Brandt's Cormorant	*	*
Pelagic Cormorant	*	*
Great Blue Heron		*
Canada Goose	*	
Mallard	*	
Harlequin Duck	*	
Long-tailed Duck	*	
Black Scoter	*	
Surf Scoter	*	
White-winged Scoter	*	
Common Goldeneye	*	
Barrow's Goldeneye	*	
Bufflehead	*	
Common Merganser	*	*
Red-breasted Merganser	*	*
Bald Eagle		*
Bonaparte's Gull	*	
Mew Gull	*	
California Gull	*	
Herring Gull		*
Thayer's Gull	*	
Glaucous-winged Gull	*	*
Black-legged Kittiwake		*
Pigeon Guillemot		*
Marbled Murrelet		*
Rhinoceros Auklet		*
Tufted Puffin		*

4.2 Impacts on Prey Resources

Fisheries and marine birds share a common prey resource base. Generally, marine birds forage at a lower trophic level (*i.e.*, lower in the food chain, on younger age-classes of fish and zooplankton) than that targeted by commercial fisheries. However, with the gradual disappearance of traditional commercial fish species, species lower in the food chain (*e.g.*, sandlance and krill) are now being targeted, bringing several fisheries into direct competition with marine birds (Gaston and Jones 1998). However, the sensitivity of seabirds to fluctuations in their prey can be used to the advantage of fisheries: many studies have shown that monitoring the diets of seabirds at colonies can predict presence and recruitment of commercially-fished prey species, such as sandlance (Bertram and Kaiser 1993; Furness and Camphuysen 1997).

Marine birds can have a noticeable impact on their prey resources (Furness 2002; PICES 2004). For example, during the breeding season alone, Rhinoceros Auklets in the eastern North Pacific were estimated to consume 326 mt of food (Vermeer and Devito 1986). Barrow's Goldeneyes and Surf Scoters in Jervis Inlet were expected to collectively eat more than 164,000 kg of blue mussels (*Mytilus edulis*) from September through May (Vermeer and Ydenberg 1989). It was also estimated that along the Oregon coast, four species of marine birds—the Sooty Shearwater, Leach's Storm-petrel, Brandt's Cormorant, and Common Murre—collectively consumed 62,562 mt of food annually, 35,800 mt of which were consumed during the breeding season (Wiens and Scott 1975). Caspian Terns nesting in the Columbia River estuary consumed an average of 8.1-12.4 million juvenile salmonids during the 1997 and 1998 breeding seasons (Roby *et al.* 2003).

4.3 Predator/Prey Distributions

Seabird densities and distributions are strongly influenced by the location of their prey (Burger *et al.* 2004; Davoren 2000; Hunt 1997; Russell *et al.* 1999).

When foraging, seabirds are predictably associated near oceanographic features causing aggregations of their prey (Haney *et al.* 1995; Hay 1992; Hunt 1997; Nel *et al.* 2001; Russell *et al.* 1999). However, natural variability in oceanographic conditions causes variation in the location and quantity of ephemeral prey (Ainley *et al.* 1996; Hay 1992), and likewise, can cause subsequent distributional shifts of foraging seabirds (Kitaysky *et al.* 2000; Obst *et al.* 1995; see section 4.4 below).

In PNCIMA, and along the BC coast, Pacific herring are one of the important forage fish influencing marine bird distributions. For example, of all sea ducks counted on aerial surveys during two winter seasons (1999-2001), herring spawn sites accounted for 32% of all birds recorded, including 50% of scoters (Breault *et al.* 2002). Herring spawn sites represented 54-81% of the total winter population of Harlequin Ducks in the northern Strait of Georgia (Rodway *et al.* 2002).

Seabird communities are also strongly influenced by spatial and temporal distributions of plankton (Jahncke *et al.* 2005; Hunt 1997; Batten *et al.* 2006). Batten *et al.* (2006) found that distinct seabird species aggregations and distinct plankton communities coincide across the north Pacific (Figure K.21). This suggests that there are linkages between lower and upper trophic levels that are unique to discrete regions or ecosystems (Batten *et al.* 2006).

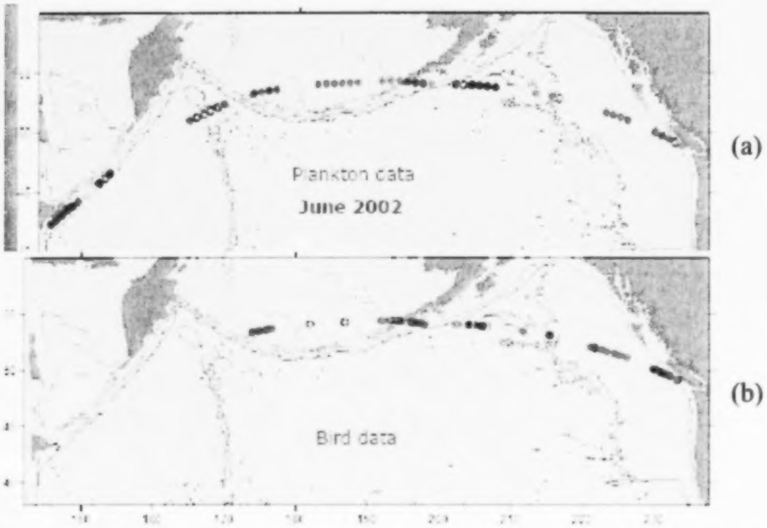

Figure K.21 Results of cluster analyses of (a) plankton and (b) seabird data gathered during the June 2002 Continuous Plankton Recorder survey. Dot colours represent different plankton and bird species aggregations during the survey (map from http://www.gem.state.ak.us/symposium/Presentations/Sonia%20Batten/Sonia%20Batten.pdf)

4.4 Oceanography

Oceanographic features, oceanic fronts, and their subsequent influence on zooplankton populations attract dense concentrations of fish and foraging marine birds (Hay 1992; Logerwell and Hargreaves 1996; Russell *et al.* 1999; Hunt 1997; Piatt *et al.* 2006). As well, specific oceanographic features correspond with habitat preferences of seabird communities; that is, seabird species exhibit different habitat preferences, associate with predictable features, and thereby distribute non-randomly throughout the marine landscape (Yen *et al.* 2005). In this way, oceanographic control of the availability and abundance of prey plays a critical role in the health and survival of seabirds in PNCIMA.

Temporal and spatial abundance of zooplankton, fish larvae, and forage fish can vary dramatically due to changes in ocean conditions that result from upwelling, El Niño/La Niña events, and Pacific Decadal Oscillations (PDOs; see also Chapter 1).

Some parts of PNCIMA experience upwelling (see Chapter 1, section 1.4), but the exact spatial extent and temporal variability of these areas is not known. The amount of upwelling that occurs in these areas is associated with broader oceanographic conditions that affect the entire North Pacific Ocean (see also Chapter 1, section 1.3, and Appendix C: Physical and Chemical Oceanography). A description of PNCIMA oceanography can be found in Chapter 1 (section 1.4) and Appendix C: Physical and Chemical Oceanography.

Water temperature, salinity, mixed water layer depth, upwelling conditions, and plankton productivity are among the oceanic characteristics known to vary during El Niño and La Niña events (Goes *et al.* 2001; Whitney and Welch 2002). In an El Niño (warmer) year, upwelling and mixing of water layers tend to be depressed. Reproductive success of several seabird species are negatively affected by El Niño events in the northeast Pacific (Bertram *et al.* 2000; 2001; Wilson 1991; Sydeman *et al.* 2005), whereas other species, such as the Horned Puffin, are able to maintain high reproductive success during El Niño events, likely because it has the ability to use alternate prey species (Harding *et al.* 2003). In La Niña (cooler) years, easterly trade winds increase in intensity, leading to increased upwelling, bringing nutrients to the ocean's surface and stimulating phytoplankton growth.

Variability in oceanic conditions occurring over longer time scales, such as PDOs, may affect marine organisms over a similar long time scale. Off the BC coast, a major shift towards a warm phase occurred in 1977 and lasted until 1999. During this period, the availability of some of the more common fish species, such as the lipid-rich capelin (*Mallotus villosus*), was reduced, while less fatty groundfish species (*e.g.*, juvenile walleye pollock, *Theraga chalcogramma*) became more abundant. Fish-eating seabirds in the region were negatively affected by this change (Burger 2002). Associated with an increase in spring sea surface temperatures, there was a decrease in both the occurrence of sand lance in the diet, and the subsequent chick growth rates and fledging success of Rhinoceros Auklets and Tufted Puffins on Triangle Island (Hedd *et al.* 2006; Gjerdrum *et al.* 2003). Similarly in Alaska, the number of Marbled Murrelets appears to be declining, possibly due to unusual ocean temperatures which have reduced the numbers of forage fish (Burger 2002). The 1970-1990 warm period in the Northeast Pacific has also been correlated with a general advancement in the timing of breeding by seabirds at Triangle Island (Hedd *et al.* 2006; Bertram *et al.* 2000); similarly, periods of warming in the North Atlantic have also been correlated with an advance in the timing of Arctic Tern breeding (Moller *et al.* 2006). Research is underway to study the effect of regime shifts on some fish species in the Pacific Ocean (McFarlane *et al.* 2002; McFarlane and MacDougall 2000; Hargreaves *et al.* 1994).

4.5 Ecological Associations among Species

Seabirds are commonly found in association with cetaceans, and certain species feed on the same prey. When pursuing prey, whales push fish and invertebrates to the water's surface, which makes them more accessible to feeding birds.

During surveys conducted by CWS, significant associations were found between occurrences of cetaceans, Fork-tailed Storm-petrels, and Common Murres off the west coast of Vancouver Island (Vermeer *et al. eds*. 1992). At Laskeek Bay, humpback whales (*Megaptera novaeanglia*) have often been sighted in the company of Ancient Murrelets, Cassin's Auklets, Sooty Shearwaters, and Rhinoceros Auklets (Laskeek Bay Conservation Society 2003). Also, phalaropes have often been seen around whales off the west coast of BC, probably because they prefer similar ocean conditions and food types (Obst and Hunt 1990). It may be possible use this apparent association to identify marine management areas that are important to both cetaceans and seabirds.

5.0 THREATS

Conservation threats and issues judged to be top concerns for marine birds in the Pacific and Yukon Region were outlined by Gebauer (2003).

Seabirds –

- introduced mammalian predators
- marine bird bycatch in fisheries
- oil pollution
- forest exploitation
- climate change
- lack of formal protection for breeding colonies and critical marine habitat

Waterfowl and Allies –

- degradation of inland and coastal habitat (development of coastal areas and changes in land use in coastal areas; exploitation of marine resources; and commercial fishing and aquaculture)
- climate change (affecting distribution and productivity of wetland habitats)
- contaminants (oil and gas, pollutants, lead, effluents)
- population issues (overabundance, problem wildlife, harvest)
- human disturbance

Shorebirds –

- land development
- human disturbance
- oil pollution and other contaminants
- spread of non-native vegetation changing beach community structures
- bird strike mortality on wires and buildings on migration routes

Several threats common to all marine bird species are summarized in the following sections.

5.1 Natural Predators

The Northwestern Crow and the Common Raven are common predators at coastal seabird colonies (Paine *et al.* 1990; Ewins 1991). On the BC coast, crows are known to depredate the eggs and young of cormorants, the eggs of Glaucous-winged Gulls and Pigeon Guillemots, and the nestlings of burrow-nesting seabirds. Human disturbances causing seabirds to leave nests can exacerbate crow predation, which opportunistically depredate eggs and chicks when parents are off the nest (Campbell *et al.* 1990b).

Gulls are also responsible for heavy predation in many seabird colonies (Gilchrist 1999), and in several cases, gull control has been implemented to help conserve sensitive or threatened species (Finney *et al.* 2003).

Bald Eagles also prey extensively on gulls, ducks, and herons during winter and are believed to be a contributing factor in the steady decline (3-5% year^{-1} since the 1960s) in the Great Blue Heron population on the BC coast (Butler and Baudin 1999).

The *anatum* subspecies of the Peregrine Falcon feeds primarily on songbirds, shorebirds, and waterfowl (Fraser *et al.* 1999), whereas the *pealei* subspecies preys mainly on colonial-nesting seabirds (*e.g.*, Ancient Murrelets, Cassin's Auklets, Leach's Storm-petrels, Rhinoceros Auklets; Nelson 1977; Fraser *et al.* 1999).

5.2 Introduced Mammals

Introduced mammals are destructive in seabird colonies because seabirds have evolved breeding habits, such as nesting out in the open or in underground burrows, which make their eggs and chicks easily accessible to terrestrial predators. Many of the world's richest seabird colonies on islands have been destroyed by introduced mammals such as rat, cat, raccoon, mink, and fox (Craik 1997; Fraser *et al.* 1999; Taylor *et al.* 2000; Smith *et al.* 2002; Williams *et al.* 2003). Several seabird populations on breeding colonies in the PNCIMA region have been drastically reduced by mammal introductions, such as Cox and Lanz islands, where raccoon and mink are still present, having extirpated seabirds and Black Oystercatchers from those islands; and Langara Island, where an intensive rat extermination program was carried out in the 1990s (Taylor *et al.* 2000). At Langara Island, recent surveys have shown that Ancient Murrelet population recovery following rat eradication is now underway (Regehr *et al.* in press). On the Queen Charlotte Islands/Haida Gwaii, raccoons are known to have caused several cases of colony abandonment by breeding seabirds (Gaston 1994); raccoons and rats are still considered to be the greatest land-based threat to seabirds nesting there (Rodway 1991).

5.3 Climate Change

As described in section 4.4, variation in oceanography has a substantial influence on marine bird abundance, distribution, and reproductive success. These relatively short-term detectable effects provide insight into the implications of global warming for seabird populations. Oceanic warming has been linked to a significant long-term decline in zooplankton production in the California Current system (Roemmich and McGowan 1995), which has in turn been linked to major declines in populations of Cassin's Auklets (Ainley *et al.* 1996; Nur *et al.* 1998) and other seabirds (Veit *et al.* 1996). Historically, oceanography and regional changes in prey bases caused by environmental and climate change has had a significant impact on the distribution and abundance of Aleutian marine birds (Causey *et al.* 2005). It has been suggested that global warming is and will continue to affect populations of seabird detrimentally, particularly those living at high latitudes. For example, adult survival and proportion of two Antarctic-breeding species were negatively affected by reduced sea ice in the context of global warming (Jenouvrier *et al.* 2005).

Distribution and productivity of wetland habitat is likely to be affected by climate change, thereby influencing populations of waterfowl (Gebauer 2003).

5.4 Fisheries Bycatch

Seabirds bycatch in commercial fisheries is considered to be the most serious global seabird-fishery issue at present (Furness 2003). Although it has been the focus of research and conservation since the 1980s, bycatch continues to be a significant human-mediated threat to seabird populations, and implicated in the population declines of several seabird species (Lewison *et al.* 2004; 2005; Furness 2003; Melvin *et al.* 2002). In British Columbia, not only were relatively abundant species with (presumed) stable populations killed as bycatch; but also, nationally and globally threatened species of seabirds were impacted by the BC fisheries (Smith and Morgan 2005).

A review of 10 years of seabird bycatch data for British Columbia has been recently published as a CWS Technical Report (Smith and Morgan 2005). Findings of this report include:

- Black-footed Albatrosses were the most common bycatch on longlines (halibut, rockfish, and sablefish fisheries; see also Geernaert 2000).
- Longlines also caught Northern Fulmar, Short-tailed Shearwater, Herring, California, and Glaucous-winged Gulls.
- Extrapolated average annual bycatch in the longline fishery was 127 birds (mostly Black-footed Albatross).
- Of all birds caught in gillnet fisheries, Common Murres (69%), Rhinoceros Auklets (23%), and Marbled Murrelets (3%) were the three most common.
- Extrapolated average annual bycatch in the gillnet fishery was 12,085 birds.
- The highest overall bycatch rates occurred in the seamount rockfish fishery (2-year average: 0.024 birds/1,000 hooks).

- This data is dependent on fisheries observer coverage, which varies by fishery and by region; a full understanding of the extent to which fisheries impact seabird populations in the North Pacific requires more observer coverage for all fishery regions.
- Estimates of species-specific bycatch may be underestimated due to the high number of unidentified and non-salvaged birds.

Mitigative measures have become a condition of licensing for many fisheries, which is expected to decrease the level of bycatch in BC (K. Morgan, Environment Canada, CWS, Sidney BC, pers. comm., 2006). However, to correctly manage for the reduction of seabird bycatch, spatio-temporal patterns of seabird abundances and timing of fisheries need to be considered together (Smith and Morgan 2005). Efforts like this are underway in Alaska, where seabird databases are georeferenced to map the areas where albatross distribution coincides with fishing effort, to highlight areas where birds are most susceptible to bycatch (Balogh and Suryan 2004).

5.5 Oiling Incidences

Oil in the marine environment is a significant threat to seabirds. Seabirds with oiled plumage lose waterproofing, buoyancy, and body heat; while ingestion of oil during preening is either acutely toxic, or has chronic impacts on immune function (Shelton 1971; Briggs *et al.* 1997).

Oil collects in the intertidal zone and affects those species which rely on intertidal foraging, such as Pigeon Guillemots, Black Oystercatchers, and several species of sea duck.

Other birds especially vulnerable to oil spills are those which form large flocks at sea or which congregate in localized areas during migration or moulting. As well, birds which dive through the surface of the water (for feeding or as an escape response, *e.g.*, diving alcids like murres, puffins, and murrelets, other diving birds such as loons, grebes, and seaducks) are generally more vulnerable to oiling than those which do not dive (gulls and petrels, which feed while sitting on the surface). Therefore, diving birds will actually pass through an oil slick when trying to escape it, as they are unable to take off directly from the surface of the water when an oil slick is encountered. These ecological realities are seen in the results of oiled bird counts, with diving alcids and diving waterbirds usually comprising the largest proportion of oil-related mortalities. For example:

- Common Murre accounted for 42-80% of seabird mortalities reported in Washington and BC coasts, after the Nestucca oil spill occurred off Washington State in December 1988 (Campbell *et al.* 1990a); generally, Common Murres are the most vulnerable species to spilled oil in the Northern Hemisphere (Wiese and Ryan 2003).

- Cassin's Auklets made up 34% of the oiled carcasses along BC shores (Rodway 1991).
- Moulting and wintering Western Grebes and Surf Scoters often form large flocks in localized areas, and are thus very are susceptible to oiling (Savard 1979; 1988).

Local oiling incidences will usually also be more harmful to seabirds which are local breeders in the particular area being assessed (Roletto *et al.* 2003; Carter 2003). CWS and the University of Victoria are currently working together to assess the extent of chronic oiling within the west coast exclusive economic zone (EEZ) of Canada. They are also developing predictive models of where seabirds will encounter oil at sea and where oiled dead birds will drift (K. Morgan, Environment Canada, CWS, Sidney BC, pers. comm., 2006).

5.6 Human-related Disturbances

Some species of colonial nesting marine birds are highly susceptible to human-related disturbances at their breeding colonies. Cormorants and puffins are especially sensitive and will readily abandon their nests if disturbed by boats approaching too closely or by humans walking through the colony. Additionally, nesting burrows can easily be damaged by human foot traffic. Declines and abandonment of Brandt's and Pelagic Cormorant breeding colonies due to disturbances have been noted in a number of places along the BC coast (Rodway 1991).

6.0 INFORMATION GAPS

- Year-round distributions of marine bird species (especially winter and at-sea foraging distributions), but see new BC seabird atlas (Kenyon *et al.* in prep.).
- Migration patterns of marine bird species.
- Marine bird winter ecology.
- Locations of colony- and species-specific critical habitats; traditional foraging, staging, and moulting areas.
- Effect of large scale, long-term, cyclic ocean variability on marine bird distribution, foraging success, and breeding success.
- Marine bird abundance and population trends over time (which will require greater survey effort and long-term monitoring at breeding colonies, and the continued use of techniques such as Capture-Mark-Recapture for estimating mortality/survivorship).

7.0 UNCERTAINTIES, LIMITATIONS AND VARIABILITY

- There is a lack of local information for many marine bird species that use PNCIMA because the region is remote, and because conducting field work there can be expensive.
- Consequently, breeding colony surveys tend to be done infrequently (often only once) and tend to cover only a small number of sites (however, see monitoring and assessment in section, 5.2, for future monitoring plans in BC).
- Almost all pelagic bird surveys conducted within Canada's west coast EEZ waters are done aboard 'Ships of Opportunity', and although these surveys have been frequent enough to provide a general understanding of seasonal variability in marine bird occurrences in the region, detailed information is lacking because the spatial and temporal distribution of these surveys has been limited.
- Overall, data for winter months and less frequented areas are sparse, but should become available in future when long-term data continue to be collected and analyzed (*c.f.* Kenyon *et al.* in prep).
- This creates a great deal of uncertainty when trying to determine 'hot spots' or critical habitat for marine birds in the PNCIMA region.

8.0 OTHER RELEVANT MARINE BIRD STUDIES IN BC/PNCIMA

8.1 International Organizations

➢ Commission for Environmental Cooperation

The Commission for Environmental Cooperation (CEC) is an international organization created by Canada, Mexico, and the United States under the North American Agreement on Environmental Cooperation. One of the CEC's projects is the 'Marine Species of Common Conservation Concern', which involves government, NGOs, and marine conservation scientists. The project is intended to identify, monitor, and conserve marine species that exhibit transboundary migrations, and so, are of common interest to the three countries. The Pink-footed Shearwater was chosen as the pilot bird species for this project (K. Morgan, Environment Canada, CWS, Sidney BC, pers. comm., 2006).

➢ Sea Duck Joint Venture

The Sea Duck Joint Venture focuses on knowledge, communication, partnerships, and conservation actions, to promote North American sea duck conservation (Sea Duck Joint Venture 2005). One of their goals is to reverse the downward population trend in 10 species of sea ducks. The venture is currently involved in a number of scoter studies in coastal BC (http://www.seaduckjv.org/ssna.html).

8.2 Government Collaborative Projects

- Research, Monitoring, and Assessments

Research Studies

CWS has conducted research on seabirds at Triangle Island (in the Scott Island group) since 1971. Studies have focused on four species that breed on the island—Cassin's Auklet, Rhinoceros Auklet, Common Murre, and Tufted Puffin—and have examined seabird distribution, diets, reproductive success, survival, and reactions to climate change and other environmental factors. Additional studies have been done on Pelagic Cormorants, Glaucous-winged Gulls, and Leach's Storm-petrels. The research conducted on Triangle Island is now a cooperative venture between CWS, BC Parks, and Simon Fraser University (Barjaktarovic and Bertram 2005).

Monitoring and Assessment

CWS has developed a long-term schedule to re-visit and monitor some of the BC seabird breeding colonies that were initially surveyed during the 1980s (Figure K.22). The organization also plans to undertake a long-term assessment of species included in Rodway's (1991) summary, plus the Northern Fulmar, to determine their population trends. Additionally, CWS intends to assess, at 5-year intervals, the conservation status of seabird populations in BC with the emphasis on four key indicator species: Cassin's Auklet, Rhinoceros Auklet, Ancient Murrelet, and Marbled Murrelet.

CWS, in cooperation with the Washington Department of Fish and Wildlife, US Fish and Wildlife Service, US Geological Service, and Washington Brant Foundation, is using satellite telemetry to study the Western High Arctic Brant, possibly one of the rarest goose stocks in the world. These Brant breed on the Parry Islands in the Canadian Arctic, winter in a very restricted area near the Canada-US border just south of Vancouver, BC. The birds are radio-tagged in the Canadian High Arctic and monitored as they migrate south. Although not well-studied to date, migration routes are likely to follow at least some part of coastal BC and this rare bird may pass through PNCIMA.

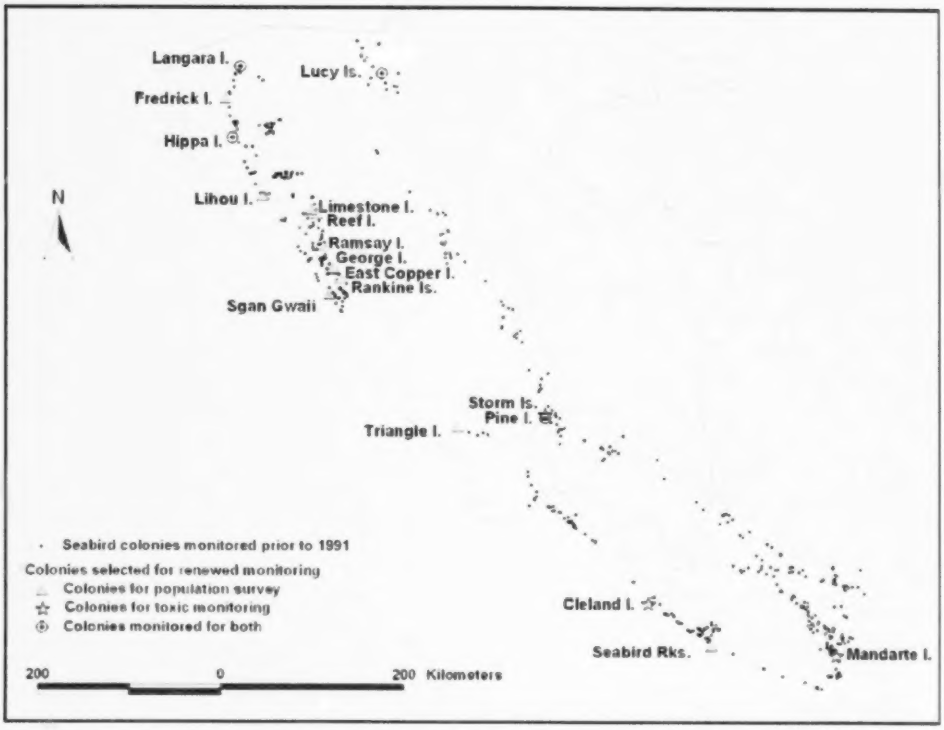
Langara I.
Lucy Is.
Fredrick I.
Hippa I.
N
Lihou I.
Limestone I.
Reef I.
Ramsay I.
George I.
East Copper I.
Rankine Is.
Sgan Gwaii
Storm Is.
Pine I.
Triangle I.
Seabird colonies monitored prior to 1991
Colonies selected for renewed monitoring
Colonies for population survey
Colonies for toxic monitoring
Colonies monitored for both
Cleland I.
Seabird Rks.
Mandarte I.
200
0
200 Kilometers

Figure K.22 Locations of seabird colonies that were surveyed in the 1980s, and locations of colonies that will be visited at regular intervals from 2002 to 2010 (data from Hipfner *et al.* 2002).

➢ Surveys

Ships of Opportunity Surveys

CWS has used 'Ships of Opportunity' to survey the relative seasonal and geographic abundance of seabirds in offshore waters (Figure K.23). The pelagic seabird database contains georeferenced information collected via 'Ships of Opportunity' from 1982 to 2005. Coverage runs from the southern tip of Vancouver Island, west to Line P (Ocean Station Papa), and north to Alaska (Figure K.23) and includes Hecate Strait, Queen Charlotte Strait, Queen Charlotte Sound, Juan de Fuca Strait, Strait of Georgia, and Johnstone Strait. These data were summarized in the BC seabird atlas (Morgan *et al.* 1991), and will be used to update a new atlas to include data to 2005; a summary of the seasonal distribution of seabirds is included in this report (Figure K.14-K.15). These surveys have resulted in several projects (see "Databases and GIS Applications", below).

These data are also being analyzed in a joint project by Point Reyes Bird Observatory (PRBO) Conservation Science and Duke University Marine Lab as a means of identifying areas that are of high biological importance to seabirds within the California Current System.

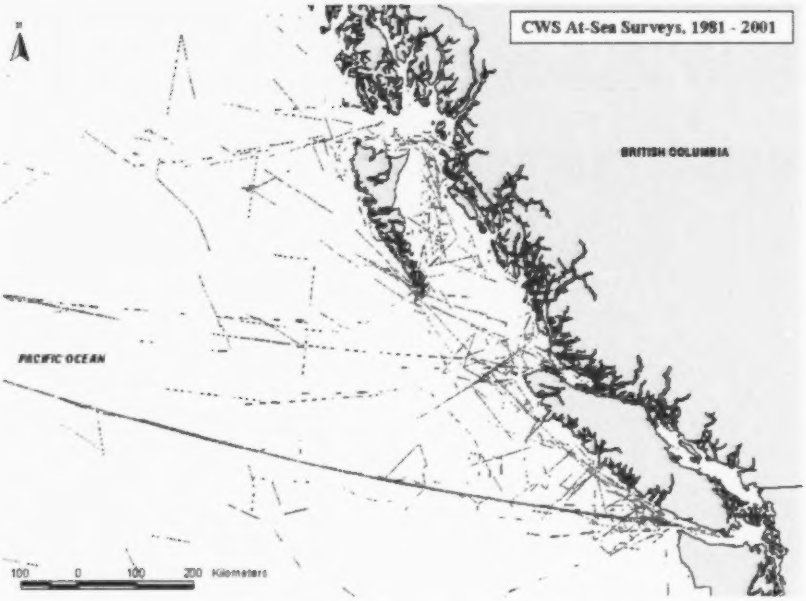

Figure K.23 Routes of CWS 'Ships of Opportunity' surveys from 1981 to 2001 (CWS unpublished data 2004).

Plankton, Seabird and Marine Mammal Surveys

CWS, PRBO, and the Sir Alister Hardy Foundation for Ocean Science have established a collaborative research program that uses Continuous Plankton Recorder surveys to monitor plankton communities and seabird and marine mammal occurrences across the North Pacific (Figure K.24). The program will help link ocean variability and plankton community with the distribution of apex predators. The program was still ongoing at the time this report was written. All plankton data are available through the Sir Alister Hardy Foundation for Ocean Science (http://192.171.163.165/).

Beginning in 1996, CWS, with support from DFO and the Coast Guard, began surveying seabirds and marine mammals along the Line P (Ocean Station Papa [OSP]) route (Figure K.24). Neither this survey route nor the Continuous Plankton Recorder route transects PNCIMA; however, they are the only known plankton survey routes close to the region.

Breeding Bird Survey

CWS and the US Geological Survey collaborate on The Breeding Bird Survey (http://www.mbr-pwrc.usgs.gov/bbs/bbs.html) to provide estimates of changes in breeding populations for many bird species. Survey effort in PNCIMA has been limited; however, it is possible to generate a list of species and number of sightings for a larger region that includes PNCIMA.

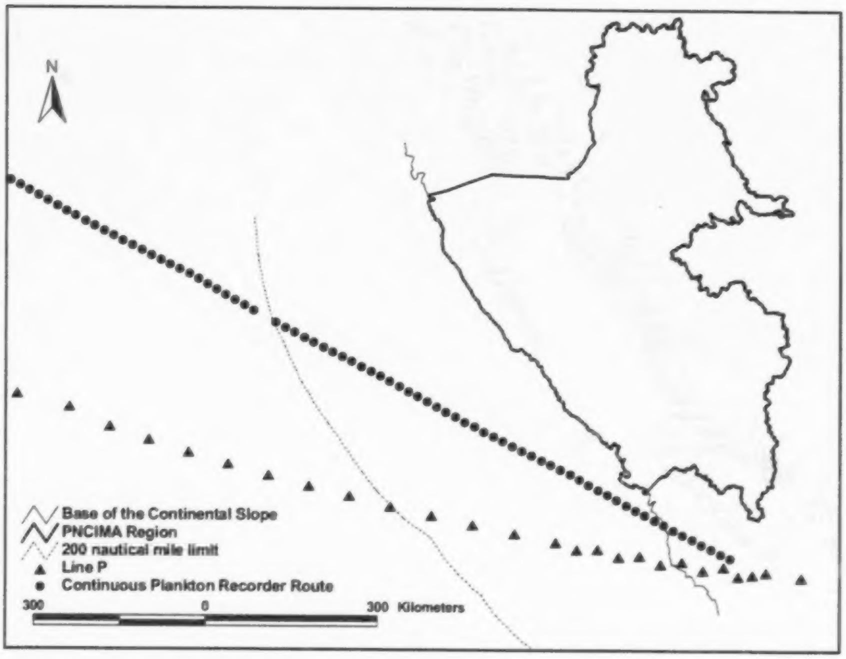
N
Base of the Continental Slope
PNCIMA Region
200 nautical mile limit
Line P
Continuous Plankton Recorder Route
300
0
300 Kilometers

Figure K.24 Continuous Plankton Recorder and Ocean Station Papa (Line P) routes in relation to PNCIMA.

➢ Databases and GIS Applications

The CWS is currently developing a number of marine-related database/GIS applications. All data will eventually be in a common Environmental Systems Research Institute-GIS format and will include baseline data on total numbers, densities, and distribution of marine birds. Projects using GIS data include:

Habitat Mapping

- *Areas of Interest*. CWS map of Marine 'Areas of Interest' for migratory birds is being updated using GIS and a more comprehensive data set; the updated report is intended for release sometime in 2007 (J. Kenyon, CWS, Environment Canada, Ladner BC, pers. comm., 2006).
- *Important Estuaries*. CWS has used GIS to assess habitat importance of BC's estuaries for many bird species in Canada's Pacific waters (see Ryder *et al.* in prep; Figure K.19).

Occurrence and Distribution Mapping/Modeling

- *BC Seabird Atlas.* Spatial and temporal distribution analysis of marine birds off the BC coast, updated to include 2005 data (CWS; Kenyon *et al.*, in prep.).
- *Waterbird Abundance/Distribution.* CWS has assembled waterbird count data into a GIS layer, to assess presence/absence, total numbers, densities, and spatial and temporal patterns of waterbird species (Badzinski *et al.* 2005).
- *Sea Ducks.* Aerial surveys of moulting sea ducks conducted by CWS during the 1980s and in 1998 will help develop a model to assess sea duck populations in estuaries throughout BC. The model will focus on winter use and be used to assist in conservation and planning efforts (Ryder *et al.* 2002).

Conservation Areas

- CWS is developing a 'conservation areas' database that will apply to federal, provincial Crown, and private lands, and will include information on land ownership, land managers, management objectives, and where applicable, provincial Crown designations of these lands. The 'conservation areas' database will be terrestrial-based but will include intertidal areas.
- CWS is using the pelagic seabird database to determine potential boundaries for the proposed Scott Island Marine Wilderness Area.

8.3 Non-Governmental Organizations (NGOs)

➢ Bird Studies Canada

Beached Bird and Coastal Waterbird Surveys

Bird Studies Canada coordinates Beached Bird and Coastal Waterbird Surveys to help monitor and conserve waterbird populations in BC. Both surveys provide consistent, systematic monitoring data within PNCIMA. Beached Bird Surveys can be used to assess background levels of chronic oiling of marine birds, to determine sources of mortality such as predation, starvation, or fisheries by-catch, and to monitor mortality trends over time. Lighthouse keepers have recently become involved in the surveys, which has made data available for some of the more remote areas of the BC coast. Coastal Waterbird Surveys are conducted once a month, and identify birds and associated habitat up to 500 m from the shoreline.

➢ Audubon Society

Christmas Bird Count

The Audubon Society's Christmas Bird Count is designed to monitor the status and distribution of winter bird populations across the western hemisphere. Christmas Bird Counts have occurred at only a few locations within PNCIMA; however, it is possible to use the count data to create a historical graph or map that shows the relative abundance of a particular bird species in a general area (http://audubon2.org/birds/cbc/hr/map.html).

- Laskeek Bay Conservation Society

This Society undertakes and supports research and long-term monitoring of wildlife populations of the Haida Gwaii (Queen Charlotte Islands) area. The Society operates a biological monitoring station on Limestone Island on the east coast of the Queen Charlotte Islands (near Laskeek Bay). Research conducted at the station focuses on seabirds, and the Society now has the longest time-series data set on seabird populations on Canada's west coast (Laskeek Bay Conservation Society 2005). Ancient Murrelets have been banded and studied for more than 14 years, and in 2003, censuses of breeding Glaucous-winged Gulls, specifically those on Kingsway Rock, Low, East Skedans, Cumshewa, and Lost islands, were initiated.

- Prince William Sound Science Center

The Prince William Sound Science Center in Alaska has conducted studies on migration ecology of various shorebird species including the Western Sandpiper, Dunlin, Long-billed Dowitcher, and Short-billed Dowitcher. The birds were radio-tagged in Mexico, and migration routes along the Pacific coast were identified and lengths of stay at stopover sites were estimated (Mary-Anne Bishop, Prince William Sound Science Center, Cordova, Alaska, pers. comm., 2006). Movements, however, were not tracked through PNCIMA.

8.4 Additional References

In addition to the references cited in this chapter, the following reports provide detailed information on marine birds on the BC coast:

Report (see reference section 9.0 for complete citation)	**Description**
Badzinski *et al.* 2005.	Provides detailed census information, trends, and discussion of survey limitations, for waterfowl, shorebirds, and seabirds along the BC coast. Surveys were concentrated in Strait of Georgia but include several areas in PNCIMA.
Burger, A.E. 2002.	Provides information on Marbled Murrelet biology, habitat associations, and conservation measures, in addition to details on nesting distribution, population estimates, and numbers of Marbled Murrelets per watershed.
Hunt, G.L., Kato, H., and McKinnell, S.M. *eds*. 2004.	Provides information on the prey of marine birds and mammals in the subarctic North Pacific Ocean. The area is divided into oceanographic domains; the northern boundary of the California Current North (just north of the Scott Islands); the Gulf of Alaska Continental Shelf runs from this point north and includes the Aleutian Islands.
Harfenist, A., Sloan, N. A., and Bartier, P. M. 2002.	Report produced by Parks Canada in support of the proposed Gwaii Haanas National Park and Heritage site; provides a detailed review of current marine bird information for Gwaii Haanas.
Hood, D.W. and Zimmerman, S.T. *eds*. 1986.	Some information on marine birds in the broader North Pacific is included in these reports.
Kenyon *et al.* in prep	Update of the 1991 BC seabird atlas (Morgan *et al.* 1991); incorporates data to 2005 and includes monthly seabird abundance and distribution throughout BC coastal and pelagic waters. This CWS publication is intended for release early in 2007.
Ryder *et al.*, in prep.	The Pacific Estuary Conservation Program has identified and mapped estuaries at a fine scale for use in conservation planning. The area covered includes the BC coast and all of the islands.
Scudder, G.G.E. and Gessler, N. *eds*. 1989.	Provides an earlier review of the Queen Charlotte Islands than Harfenist *et al.* (2002) and includes marine bird information.
Strong *et al.* 2002; Hall *et al.* 2004; LGL Limited 2004; Offshore Oil and Gas Research Group 2004; Ricker 1989; Ricker and McDonald 1992; 1995; Booth 2000.	Brief summary information on marine birds is included in these oil and gas-related environmental reports. Similar summaries are presented in these provincial reports on human use issues in the Central and North Coast areas.
COSEWIC status reports http://www.sararegistry.gc.ca/search/advSearchResults_e.cfm?stype=doc&docID=18	Status reports are available for the following species: • Short-tailed Albatross • Pink-footed Shearwater • Ancient Murrelet

9.0 GLOSSARY

Apex predators – Apex predators, also known as alpha predators or superpredators, are animals that are often at the end of long food chains and which are not preyed upon in the wild. Apex predators help maintain the ecological balance of their respective ecosystems by keeping populations of prey animals in check.

Bathymetric – Measurement of the depth and bottom contours and slopes of a water body; underwater topography.

Ephemeral – Characterized as episodic and lasting a short duration.

Isotopic signatures – The ratio of stable or unstable isotopes of any particular elements found in a studied material. The atomic mass of different isotopes affect their chemical kinetic behaviour, leading to natural isotope separation processes ("fractionation"). In the case of biological studies, the fractionation of carbon isotopes (12C/13C) and nitrogen isotopes (13N/14N) are used to trace the biological origins of diet.

Lipid-rich – High in fat.

Radiotelemetry – In biology, this refers to tracing or tracking a transmitted radio signal from a radio transmitter attached to an animal. Each individual animal is identified by a unique radio transmitter frequency and its movements are detected by a radio receiver. This radio receiver may be operated a person who is stationary or searching (for example, in a vehicle); or remotely, by a stationary data collection computer.

Satellite telemetry – Tracking or tracing a transmitted satellite signal attached to an individual animal. Usually this signal is received by satellites and downloaded at intervals by researchers. This technology allows a much greater range of detection than that from radiotelemetry.

Sympatrically-breeding – Refers to different species that breed in the same geographic area.

Temporally – Over time.

Upwelling – An oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-deplete surface water. There are at least five types of upwelling: coastal upwelling, large-scale wind-driven upwelling in the ocean interior, upwelling associated with eddies, topographically-associated upwelling, and broad-diffusive upwelling in the ocean interior.

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